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Loose and baled corn cob management and storage in field effects on subsequent crop growth and soil health

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Loose and baled corn cob management and storage in field effects on subsequent crop growth and soil health

by

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DEDICATION

To my family, friends, and girlfriend, for their care, sacrifice, love, and buoyancy.

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LIST OF ABBREVATIONS

AC	Ames central site
ρ_b	Bulk density
C	Carbon
CO_2	Carbon dioxide
CT	Conventional tillage
ERI	Emergence rate index
ENW	Emmetsburg northwest site
GHG	Greenhouse gas emission
I_r	Water infiltration rate
MBC	Microbial biomass carbon
N	Nitrogen
N_2O	Nitrous dioxide
NT	No-tillage
SOC	Soil organic carbon
STN	Soil total nitrogen
TC	Total carbon
TN	Total nitrogen
U.S.	United States
WSA	Water stable aggregates
SPR	Soil penetration resistance

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ABSTRACT

Companies in the U.S have started using corn (*Zea mays* L.) residue as feedstock for cellulosic ethanol production. However, concerns including field storage and removal methods effects on crop growth and development, soil health, and environmental quality have been raised requiring the investigation of management and strategies to mitigate such effects. In the Mid-west corn cob have being utilized as feedstock material for cellulosic ethanol production in addition to corn residue. Nevertheless, there are many management issues that need to be addressed in order to efficiently store and remove corn cob from the field with minimum damage to subsequent crops and soil health. The current practices include the storage of loose corn cob mixed with corn residue as piles and bales at the edge of harvested fields over winter for later use in ethanol production. The corn cob residue refers to the mixture of corn cob and corn stover in the loose and baled corn cob treatments used in this experiment. Unfavorable plant growth responses have been observed after storing corn cob residue in the field. The objectives of this study were 1) to investigate the effects of loose and baled corn cob residue storage methods and management practices on plant development and crop yield, 2) evaluate and understand the effects of both methods on soil health, and 3) determine the effects of different amounts of loose corn cob residue left after removal and management practices on greenhouse gas (CO_2 and N_2O) emission and management practices to mitigate such effects.

The study investigated two storage methods at two different sites that were established in fall of 2010. Trials ran through the fall 2012. The loose corn cob residue study was conducted at the Agronomy Research Farm at Iowa State University located near Ames, Iowa (AC site). The soil type is Canisteo silty clay loam (Fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls) and Harps loam (Loam, mixed, superactive, mesic Typic Calciaquolls). The

treatments for the loose corn cob residue method consisted of two randomized tillage systems conventional tillage (CT) and no-tillage (NT), which represented the main treatment. Each tillage system was split into five corn cob residue treatments as Control, Removed Residue (7.5 cm applied in the fall and completely removed early spring), 2.5, 5.0, and 7.5 cm corn cob residue depths randomly assigned at each tillage treatment and replication. Then each corn cob residue treatment was split to receive four N fertilizer rates of 0, 90, 180, and 270 kg N ha^{-1} randomly assigned at each corn cob residue treatment and replication. The N fertilizer was 32% liquid UAN (NH_4NO_3), which was side-dressed and injected in May after planting using a spoke point injector. The AC site was planted on 6th May, 2011 and 14th May, 2012 using a 111 day maturity corn variety (P33W84) with a seeding density of 79,000 seeds ha^{-1}.

The second study was established at a Northwest Iowa farmer's field near Emmetsburg and near the POET, Biorefinery plant (ENW site). The soil type is Clarion loam (Fine-loamy, mixed, superactive, mesic Typic Hapludolls). The ENW site used a square corn cob residue bale as a storage method, in which bales were placed in the field after harvest and stored over winter, but removed in the spring before planting. The main treatment consisted of corn cob residue left after bales removal: 1) Corn cob residue left after bales removal as a result of breakdown of bales if any, 2) corn cob residue completely cleaned or removed from each plot, and 3) the control treatment, where no bales were placed on plots. Each of the corn cob residue treatments were split into four N fertilizer rates of 0, 90, 180, and 270 kg N ha^{-1} and randomly assigned at each corn cob residue treatments. The different N fertilizer rates were hand applied using granular urea in May after planting. The ENW site was planted on 5th May, 2011 and 25th April, 2012 using a 111 day maturity corn variety (P0448AM1), with a seeding density of 89,000 seeds ha^{-1}.

Field data collection and measurements for plant, soil, and other parameters were conducted at both sites on weekly, monthly, and seasonal basis. These measurements included plant growth and development parameters, soil physical, chemical, and biological properties such as, soil organic carbon (SOC), soil total nitrogen (STN), microbial biomass (MBC), soil pH, organic acids (only at the AC site), soil penetration resistance (SPR), water stable aggregates (WSA), soil bulk density (ρ_b), and soil water infiltration rate (I_r only at the AC site only). Also, measurements of greenhouse gas emission (CO_2 and N_2O) were monitored along with soil mineral N (NO_3–N and NH_4–N), soil temperature, and moisture at the AC site only.

The findings of the loose corn cob residue study suggest that plant growth and development were negatively affected by the presence of loose corn cob residue. In general, the emergence rate index (ERI), extended plant leaf heights, above-ground biomass and grain yield are negatively affected when corn cob residue is left on the soil surface after pile removal. Tillage systems show no difference in preventing the effects of corn cob residue, but it was observed that NT showed a slight advantage over CT, for plant growth and development. As expected N fertilizer at the agronomic rate (180 kg/ha) helped plant development and growth. Above-ground biomass and grain organic C and N concentrations were affected by the increase of N fertilizer rates, but not by other management practices such as tillage or corn cob residue treatments.

Additionally, soil biological and chemical properties such as, SOC, STN, soil pH, and organic acids were not affected by different management practices. Changes in MBC values were affected at different times in the growing season by corn cob residue treatments. The highest soil MBC concentration was observed at the 2.5 cm and 7.5 cm corn cob residue treatments, especially in June and July (mid-summer) compared to the control and removed corn cob residue treatments. Also, soil organic acids concentrations of oxalic and butyric were the most detectable in the soil with all residue treatments in 2011 only.

However, the findings suggest that soil physical properties such as, WSA, ρ_b, SPR, and I_r were affected by the amounts of corn cob residue left on the soil surface. The results showed a decrease in soil macro-aggregates percentage across all corn cob residue treatments due to seasonal variability as moisture condition changed. The SPR was affected by the amount of corn cob residue left on the soil surface and the degree of residue removal, where machinery and human traffic led to increase in soil compaction. Soil ρ_b was lower at the 0-7.5 cm soil depth in general compared with lower soil depths, and I_r was also affected by corn cob residue under the CT tillage system, where 2.5 cm and 7.5 cm corn cob residue showed higher I_r than that under control and removed at all N fertilizer rates.

At the AC site soil CO_2 and N_2O were monitored along with soil mineral N (NO_3–N and NH_4–N), soil moisture, and soil temperature. The findings from the study suggested that soil CO_2 and N_2O emission were higher under the 2.5 cm and 7.5 cm corn cob residue treatments than the control and removed treatments. Soil moisture and soil temperature were also affected by the level of corn cob residue treatments covering the soil surface, which subsequently affected soil CO_2 and N_2O emission. Also, soil N_2O emission was affected by N fertilizer rates, where higher N fertilizer rates caused higher soil N_2O emission. It was also observed that dry conditions in 2012 decreased soil CO_2 and N_2O emission across all management practices, due to lower soil moisture and high soil temperatures. The soil CO_2 and N_2O emission were affected by corn cob residue left after removal, where areas with excessive amounts of corn cob residue on soil surface showed greater CO_2 and N_2O emission rates than clean areas.

In the corn cob residue bale study, findings suggest that plant growth and development are not greatly impacted by the presence of corn cob residue left after bale removal from the site. It was observed that a minimum amount of corn cob residue was left on the soil surface after bales removal. In general, ERI, extended plant leaf heights, plant population, vegetative growth stages, above-ground biomass, and grain yield for clean and left corn cob residue treatments were slightly lower than control where no corn cob residue bales were placed. Over the study period no changes were observed in organic C and N concentrations of the above-ground biomass and grain.

Nonetheless, corn cob residue bale storage on the field showed some changes in the SOC and STN contents at different soil depths. In general, changes in SOC and STN contents were similar across all corn cob residue treatments within each soil depth. However, at the top 7.5 cm soil depth greater SOC and STN content were observed compared to lower soil depths across all corn cob residue treatments. Also, soil pH at the top 7.5 cm soil depth was lower than that at lower soil depths across all corn cob residue treatments. Soil MBC concentration was also monitored during the corn cob residue bales study, where in general no corn cob residue treatment effect on MBC was observed within each soil sampling period for both years. However, greater MBC values were observed in the fall for both years across all corn cob residue treatments than early spring. The increase in MBC concentrations can be due to increase in organic matter and its decomposition when left on the soil surface after harvest and removal of corn cob residue bales.

At the ENW site physical properties were affected by the storage of corn cob residue bales, where soil macro-aggregates stability and associated C content across all corn cob residue treatments showed a decline by the end of the experiment. While an increase for those parameters associated with micro-aggregates was observed, changes in ρ_b were mostly found at the top 7.5 cm soil depth across all corn cob residue treatments which are consistent with the increase in SPR values at the same depth. The greatest SPR values are observed in areas where corn cob residue bales were stored.

The most effective practices in mitigating corn cob residue effects on plant growth and development, soil physical and chemical properties, and soil CO_2 and N_2O emission are adequate control of field machinery traffic for corn cob residue removal and corn cob residue cleaning. Field machinery for removal of loose and baled corn cob residue should be conducted under suitable conditions (i.e. dry soil condition) to minimize soil compaction during the removal of corn cob residue left on the soil surface. Such management practices can reduce corn cob residue effects on corn productivity and soil health (physical, biological, and chemical optimum functions). Also, an adequate application of N fertilizer rates will help reduce corn cob residue effect of N-immobilization and subsequent effects on plant development.

CHAPTER I

GENERAL INTRODUCTION

The average daily consumption of petroleum in the United States (U.S.) for 2012 was 18.6 million barrels per day, making it the world's largest petroleum consumer. The U.S. foreign petroleum dependence has declined since peaking during 2005; however forty percent of U.S. net petroleum consumption still came from Western Hemisphere countries (EIA, 2013). Petroleum consumption is expected to increase with the continuous rise of human population, while industry forecasts speculate the maximum production of economically extractable petroleum is either approaching or already had (Almeida and Silva, 2009; Bardi, 2009; Campbell, 2002). Fundamental biofuel production and research in the U.S. started in 1978 and kept a steady pace until 2004. At this point the rising price of petroleum and the desire of the U.S. to reduce dependence on foreign oil lead to a dramatic increase in biofuel industry (Jessup 2009). At present, public and private funding sources have increased the number of refineries and bioenergy research centers (Hoekman, 2009).

Many renewable sources of energy have been used (biomass, solar, wind, geothermal, etc.) to create sustainable energy. Currently, biomass (i.e., grain, leaves, stover, cobs, etc.) is believed to be the only viable alternative renewable energy for fossil fuels (Dwivedi et al., 2009). In the U.S. the main feedstock material for biofuel production is corn (*Zea mays* L.) grain, which is high in starch/sugar. Corn residue has been targeted as feedstock for cellulosic ethanol production due to its abundance, creating a demand for ethanol plants (Dwivedi et al., 2009; Schubert, 2006). The removal of crop residue may require farmers to change their current tillage and fertilization management to minimize negative impacts on soil and the environment. The first-generation of ethanol production used food annual crop alternatives as feedstock, however new technology allows us to produce ethanol from cellulose which is a common compound in all plants.

In addition to corn residue as a source for cellulosic ethanol, corn cob is another feasible option for cellulosic ethanol production (Avila-Segura et al., 2011) across the Mid-west due to the prevalence of corn-based agriculture. New cellulosic ethanol technology offers more options for fuel production and could allow farmers to boost their income by selling corn residue. Some bioenergy refineries in Iowa have started utilizing corn cob in mixtures with corn residue as a feedstock for cellulosic ethanol (Service, 2007). Thus, some biorefineries have investigated two methods of collection and storage of corn cob residue for cellulosic ethanol production. The corn cob residue refers to the mixture of corn cob and corn stover for the loose (70% corn cob and 30% corn stover) and baled (30% corn cob and 70% corn stover) corn cob residue treatments used in this experiment. The first method involves collection of loose corn cob residue and the second method involves bailing corn cob residue. Loose or baled corn cob residue is piled or stacked at the edge of the field after harvest for the duration of winter until the following spring. Field observations of corn planted where corn cob residue were stored over winter exhibited detrimental growth symptoms as documented from previous years fields observations. The dramatic effects of corn cob residue on soil health and ultimately yield of the following crop were a concern.

Management practices associated with storing and removal of corn cob and residue could cause detrimental effects to soil health. The collection and storage of corn residue in the field involve significant equipment use and traffic on the field, which can lead to soil compaction, causing surface runoff, soil erosion, and ultimately decrease in above-ground biomass production (Wilhelm et al., 2004; Graham et al., 2007). Crop residue plays an important role in improving and keeping adequate soil physical, biological, and chemical property conditions which are essential to maintain soil productivity and healthy crops (Karlen et al., 1994). Therefore, crop residue management is necessary in order to provide an optimal seed zone condition for corn seedling development and plant growth (Swan et al., 1996). However, excessive surface residue cover may affect corn growth and development by influencing soil temperature, which will consequently lead to a decrease in yield (Kaspar et al., 1990; Bollero et al., 1996).

The physical and biological effects of corn cob residue storage and the removal process were observed during a field study at Emmetsburg, Iowa at four different farms (unpublished work for loose corn cob residue storage study, Al-Kaisi and Elmore, 2010). We hypothesized that the crop development and soil quality problems occurred in the field after the corn cob residue storage process. The problem may be due to high amounts of corn cob residue left after removal process, or remnant of stored bales in the field and associated equipment traffic. Therefore, the introduction of management practices such as, tillage system and N fertilization may mitigate the potential effects on crop performance and soil health. The objectives of this study were to examine a set of management practices such as tillage, corn cob residue amount, N fertilization rates, and their interaction effects on (i) crop growth and development, (ii) soil chemical, biological, and physical properties and (iii) greenhouse gas emission (only at the AC site) in Northwest and Central Iowa. The research questions we will be addressing in this research are:

1. How does the storage and removal of the loose and baled corn cob residue in field affect corn growth and yield?
2. What are the effects of the loose and baled corn cob residue on soil chemical, biological, and physical properties?

3. What management practices, if any, are necessary to mitigate such effects on subsequent crops and soil health?

THESIS ORGANIZATION

This thesis is organized into 5 chapters, each one of them addressing aspects to be believed important to our understanding of the effects of corn cob residue management on plant growth and development, soil health, , and GHG emission. The first chapter is a general introduction that outlines the importance of this study. The second chapter examines the impacts of corn cob residue on plant growth and development, above ground biomass, grain yield, and total carbon and nitrogen (TC & TN) in grain and stover. The third chapter focuses on soil organic carbon (SOC), soil total nitrogen (STN), organic acids, and soil pH, bulk density (ρ_b), water stable aggregates (WSA), soil penetration resistance (SPR), and water infiltration rate (I_r). The fourth chapter focuses on greenhouse gas (GHG) emission as affected by different tillage systems, corn cob residue amounts, nitrogen fertilization, soil temperature, and water content. The fifth chapter summarizes conclusions of the research findings. Evaluations of these parameters will help us understand the effects of storage and removal of corn cob residue for cellulosic ethanol production on productivity and soil health.

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CHAPTER 2

LOOSE AND BALED CORN COB RESIDUE EFFECTS ON PLANT DEVELOPMENT, GROWTH, AND PRODCUCTIVITY

ABSTRACT

Early corn (*Zea mays* L.) growth and development in the Corn Belt is usual affected by wet soil with low temperatures early in the growing season, thus corn residue management is essential to provide a good corn seed bed. Bioenergy companies have started exploring the potential use of corn residue as feedstock for cellulosic ethanol production, and are investigating several methods of corn residue storage and removal. Currently, the storage methods used include piling and baling loose corn cob residue at the edge of harvested fields for storage over winter, until removal the following spring. Unfavorable plant growth symptoms were observed with some methods of storing corn cob residue in the field. The objectives of this study are to investigate the effects of loose and baled corn cob residue storage methods and removal on plant growth and development, crop yield, and potential management practices to mitigate such effects.

The study investigated two storage methods at two different sites that were established in the fall of 2010, through the fall of 2012. The loose corn cob residue study was conducted at the Agronomy Research Farm at Iowa State University located near Ames, Iowa (AC site). The soil type is Canisteo silty clay loam (Fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls) and Harps loam (Loam, mixed, superactive, mesic Typic Calciaquolls). The treatments for the loose corn cob residue method consisted of two tillage systems of conventional tillage (CT) and no-tillage (NT), which represented the main treatment. Each tillage system was split into five corn cob residue treatments as Control, Removed Residue (7.5 cm applied in the

fall and completely removed early spring), 2.5, 5.0, and 7.5 cm corn cob residue depths randomly assigned at each tillage treatment and replication. Furthermore, each corn cob residue treatment was split to receive four N fertilizer rates of 0, 90, 180, and 270 kg N ha^{-1} randomly assigned at each corn cob residue treatment and replication. The N fertilizer was 32% liquid UAN (NH_4NO_3), which was side-dressed and injected in May after planting, using a spoke point injector (Baker et al., 1989). The AC site was planted on 6^{th} May, 2011 and 14^{th} May, 2012 using a 111 day maturity corn variety (Pioneer, P33W84) with a seeding density of 79,000 seeds ha^{-1}.

The second study was established at a Northwest Iowa farmer's field near Emmetsburg and near the POET, Biorefinery plant (ENW site). The soil type is Clarion loam (Fine-loamy, mixed, superactive, mesic Typic Hapludolls). At the ENW site, square corn cob residue bales were used as a storage method, with which bales were placed in the field after harvest and stored over winter but removed in the following spring before planting. The main treatment consisted of corn cob residue left after bales removal: 1) Corn cob residue left on soil surface as results of breakdown of bales if any, 2) corn cob residue were completely cleaned or removed from each plot, and 3) control treatment, where no bales were placed on plots. Each of the corn cob residue treatments were split into four N fertilizer rates of 0, 90, 180, and 270 kg N ha^{-1} and randomly assigned at each corn cob residue treatments. The different N fertilizer rates were hand applied using granular urea in May after planting. The ENW site was planted on 5^{th} May, 2011 and 25^{th} April, 2012 using a 111 day maturity corn variety (Pioneer, P0448AM1), with a seeding density of 89,000 seeds ha^{-1}.

The agronomic parameters measured in the field study consisted of emergence rate index (ERI), vegetative growth stages, extended plant leaf height, above-ground biomass, final plant population, corn grain yield, and organic C and N concentrations for plant and grain. Greenhouse experiments were also conducted to observe the effects of simulated loose corn cob storage and corn cob leaching extraction effects on plant growth and development. The greenhouse experiments were conducted at the Agronomy Department Greenhouse facility at Iowa State University, where vegetative growth stages, extended plant leaf height, and above ground biomass were measured during these studies.

The field study findings suggest that plant growth and development were negatively impacted by the presence of loose corn cob residue. In general ERI, extended plant leaf heights, above-ground biomass, and grain yield were negatively affected by the increase of corn cob residue depths left on soil surface. Tillage systems show no effects on those agronomic parameters across all corn cob residue depths. However, it was observed that NT had slight advantage over CT under drought conditions. Nevertheless, the effects of corn cob residue after bales removal showed no changes on those agronomic parameters. Above-ground biomass and grain organic C and N concentrations were affected, in both studies (loose and baled residue), by the increase of N fertilizer rates, but not by other management practices such as tillage or corn cob residue treatments. Also, the greenhouse experiments showed that plant growth inhibition can be positively correlated with the amount of corn cob residue store in the field, confirming the negative impacts of storing corn cob residue.

The findings suggest that the most mitigating practices in reducing corn cob residue effects on plant growth, development, and yield are adequate N availability, especially with loose corn cob residue left on the soil surface to prevent any N immobilization. The other consideration in reducing corn cob residue effects is the degree of removal of corn cob residue from the storage area. Such management practices were sufficient enough to reduce the effects of corn cob residue on yield and biomass production. A balance approach of adequate N fertilizer rates and removal of loose corn cob residue from the storage areas are essential to mitigate loose corn cob residue effects.

INTRODUCTION

Energy independence has brought the U.S. to look into biofuels as an alternative for fossil fuels. The main feedstock material for biofuel production is corn (*Zea mays* L.) grain, which is high in starch/sugar. However, corn residue has been also targeted as feedstock for cellulosic ethanol production due to its abundance, encouraging bioenergy industry to establish ethanol plants (Dwivedi et al., 2009; Schubert, 2006). Furthermore, cellulosic ethanol may have the potential to reduce greenhouse gas emission and fossil fuels dependence (Wilhelm et al., 2004; Graham et al., 2007). However, the removal of crop residue may require farmers to change current tillage and fertilization management practices to minimize damages to crop growth, development, and grain yield.

The first-generation of biofuel production used corn grain as feedstock. However other emerging technologies have been examined to produce ethanol from cellulose sources such as; corn residue and corn cob. Currently, production of cellulosic ethanol is more expensive and complex than from starch. Therefore, biorefineries have investigated several methods of collection and storage of corn cob and residue in order to efficiently produce biofuels. The first method involved storage of loose corn cob residue (over 70% corn cob and 30% corn stover) at the edge of fields. While the second method involves corn cob residue baled in square or round bales (70% corn stover and 30% corn cob). Generally, loose or baled corn cob residue are piled or stacked at the edge of the field after harvest for the duration of winter until the following spring. Field observations of especially, corn planted where loose corn cob residue were stored over winter exhibited lower plant growth, development and yield the following season.

In the Corn Belt region where soils have inherently fine texture and somewhat poorly-drained, crop residue management is necessary to provide an optimal seed zone condition for corn seedling development and plant growth (Swan et al., 1996). Outside storage of corn cob residue in loose piles in the field can cause detrimental effects on soil health due to heavy and frequent equipment traffic, where those practices can lead to soil compaction, surface runoff, soil erosion, and subsequent decrease in above-ground biomass and grain production (Wilhelm et al., 2004; Graham et al., 2007). Crop residue plays an important role in improving soil biological, physical, and chemical property conditions, which are essential to maintaining soil organic matter, productivity, and healthy crops (Karlen et al., 1994). However, surface residue covering poorly-drained soils, if not managed correctly may cause slow growth and development due to low soil temperature (Kaspar et al., 1990; Bollero et al., 1996; Fortin and Pierce, 1991), which often leads to slow plant emergence and N mineralization (Al-Kaisi and Kwaw-Mensah, 2007).

Residue cover left on the soil surface after harvest can influence N availability early in the growing season, where cold soil temperatures slow down soil organic C and N mineralization and subsequent plant N use or accumulation (Al-Kaisi and Licht, 2004; Licht and Al-Kaisi, 2005; Mehdi et al., 1999; Sanju and Singh, 2001). Consequently, this will affect corn plant development due to low N availability early in the season leading to reduction in plant N uptake, which can affect grain yield. Regardless of tillage system, grain yield responded positively to additional N rate applications (Al-Kaisi and Waskom, 2002). The use of CT, especially in poorly-drained soils have led to positive responses in mitigating residue effects by increasing soil temperature and water evaporation early in the spring (Mahboubi and La, 1998), which potentially can improve organic N mineralization. It was also found that corn plants developed faster under CT system and showed greater plant development and deeper root system compared with NT system (Fortin, 1993). Subsequently, faster developing plants are better in tolerating temporary weather stress than slow to develop plants.

Currently, few studies have evaluated the feasibility of corn cob as a primary feedstock for cellulosic ethanol due to its lower nutrient replacement cost (Halvorson and Johnson 2009; Johnson et al., 2010; Avila-Segura et al., 2011). Thus, the sustainability of the removal and the storage method for corn cob will depend heavily on the cropping system (Doran et al., 1984), climate and soil type (Mu et al., 2008), which need to be specified regionally. We hypothesized that potential crop growth and development problems occurred in the field after the corn cob residue storage process. It may be due to high amounts of corn cob residue left after removal process, or remnant of stored bales in the field. Thus, creating biological and physical conditions that are not favorable for normal plant growth and development. The objectives of this study were to examine a suite of potential management practices, such as, tillage, N fertilizer rates, corn cob residue amounts, and their interaction effects on crop development and productivity in Central and Northwest Iowa.

MATERIAL AND METHODS

Experimental sites and treatments

Loose corn cob experiment (AC site)

The study was established in the fall of 2010 on a Canisteo silty clay loam (Fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls) and Harps loam (Loam, mixed, superactive, mesic Typic Calciaquolls) soil association at the Iowa State University, Agronomy Research Farm (AC site) located in Central, Iowa (42.0^{o}'N; 93.8^{o}'W) . Before the study was established in the fall of 2010, the AC site was in a corn-soybean [*Glycine max* (L.) Merr.] rotation under conventional tillage (CT), which was chisel plowed in the fall and chisel plow plus disk in the spring. Source of N fertilizer used was liquid urea-ammonium nitrate 32% N (UAN), which was side-dressed injected in May after planting using agronomic rates of 170 kg N ha^{-1} (Blackmeter et al., 1997). Also phosphorus and potassium fertilization were applied as needed to maintain optimum fertility levels so as not to restrict corn or soybean growth.

The average annual temperature and annual precipitation at the AC site for 2011 was 8.7 ^{o}C and 807 mm, respectively. During 2012, the average annual temperature was 11.4 ^{o}C and annual precipitation was 512 mm (Fig. 2.1). Treatments were established to monitor the changes in plant growth and development under loose corn cob residue in a randomized complete block design with split-split arrangement with three replications in a continuous corn cropping system for the duration of the study. The dimension of each plot was 6.1 m wide by 7.6 m long with three meter borders between plots and replications.

The AC site consisted of two randomized tillage systems conventional tillage (CT) and no-tillage (NT), which represents the main treatment. Tillage system CT was conducted in the spring within a week after corn cobs residue removal treatment was performed, using a commercially available model with straight shanks and twisted sweeps. The shanks were mounted on four tool bars in a staggering order to ensure an effective spacing of 30 cm between shanks. The depth of tillage with chisel plow was 22-25 cm. A field cultivator was then used for secondary tillage, using a horizontal implemented frame section with straight shanks and smoothing arrow at the end. The NT system has no disturbance besides application and removal of corn cob residue (removed treatment only), seed planting, and N fertilizer application.

Each tillage system was split into five corn cob residue treatments as Control, Removed Residue (7.5 cm applied in the fall and completely removed early spring), 2.5, 5.0, and 7.5 cm corn cob residue depths randomly assigned at each tillage treatment and replication. The desired corn cob residue treatments were based on our first field evaluation at four different sites in Emmetsburg, Iowa in 2009-2010, where corn cob residue were piled in-field areas of 9.1 m width by 30.5 m long. After, corn cob piles were removed by farmers; noticeable amount of residue ranging from 2.5 to 7.5 cm depth of corn cob residue was left on the soil surface (Fig.2.2). In the fall of 2010, corn cob residue treatments were established for the 2011 rowing season based on the above observations using loose corn cob residue (70% corn con and 30% corn stalks and leaves) provided by POET Biorefinery from Emmetsburg, Iowa. The corn cob residue for each treatment depth was based on spreading corn cob residue on an experimental plot, which was weighted on a field scale to determine equivalent amount to each designed depth. The corn cob residue equivalent to each treatment depth was then hauled and spread using hand-hoes to each respective plot using a field cart. For the 2012 season, the same corn cob residue treatments were kept on the same plots, except for the removed residue treatment, where fresh corn cob residue was applied again in the fall of 2011 after corn harvest and removed early spring 2012.

Furthermore, each corn cob residue treatment was split to receive four N fertilizer rates of 0, 90, 180, and 270 kg N ha^{-1} randomly assigned at each corn cob residue treatment and replications. The N fertilizer source was 32% liquid UAN (NH_4NO_3), which was side-dressed and injected in May after planting, using a spoke point injector (Baker et al., 1989). The AC site was planted on 6th May, 2011 and14th May, 2012 using a 111 day maturity corn variety (Pioneer, P33W84) with a seeding density of 79,000 seeds ha^{-1}.

Corn cob bales experiment (ENW site)

The study was established in the fall of 2010 on a Clarion loam (Fine-loamy, mixed, superactive, mesic Typic Hapludolls) soil association on a field near Emmetsburg in northwest

Iowa (ENW) (43.1^{o}'N; 94.7^{o}'W). Before the study was established in the fall of 2010, the ENW site was in corn-soybeans [*Glycine max* (L.) Merr.] rotation under conventional tillage (CT), which was chisel plowed in the fall and chisel plus disk in the spring. Source of N used was liquid urea-ammonium nitrate 32% N (UAN), which was side-dressed injected in May after planting using agronomic rate of 170 kg N ha^{-1} (Blackmeter et al., 1997). Also, phosphorus and potassium were applied as needed to maintain fertility level so as not to restrict corn or soybean growth.

The average annual temperature and annual precipitation for 2011 was 7.4 ^{o}C and 709 mm, respectively. In 2012, the average annual temperature was to 9.8 ^{o}C and annual precipitation was 559 mm (Fig. 2.9). Treatments were established to monitor changes in plant growth and development under corn cob bales residue (70% corn stalks and leaves and 30% corn cob) in a randomized complete block design with split-split arrangement with CT system, and three replications in a continuous corn cropping system for the duration of the study. The dimension of each plot size was 6.1 m wide by 7.3 m long with three meters borders between plots and 12.2 m wide buffer zone between corn cob bales treatments. The buffer zones between corn cob bales were established to prevent excessive snow accumulation during winter to ensure uniform moisture distribution in areas between corn cob bales.

The ENW site consisted of three randomized corn cob residue treatments after bales removal, which represents the main treatment. Corn cob bales placement occurred in the fall of 2010 and 2011 after harvest, then corn cob bales were removed the following spring of each year. Corn cob bale management at the ENW site consisted of the following treatments after bales removal: 1) corn cob residue left on the soil surface as results of bales breakdown during the removal process if any, 2) corn cob and other residue were completely cleaned from each plot after bale removal, and 3) control treatment where no bales were placed on plots (Fig. 2.10). Corn cob bales and residue treatments were used on the same plots every year. Furthermore, each of the corn cob residue treatments was split into four N fertilizer rates of 0, 90, 180, and 270 kg N ha^{-1}. The different N fertilizer rates were weighed using portable scale (ULINE H-1651 shipping supply specialist, Pleasant Prairie, WI) within a range of + /– 0.05 kg granular urea. Then each N fertilizer rate was hand applied in May after planting at each related plot. The ENW site was planted on 5th May, 2011 and 25th April, 2012 using a 111 day maturity corn variety (Pioneer, P0448AM1), with a seeding density of 89,000 seeds ha^{-1}.

Greenhouse preparation and treatments 2010

A greenhouse experiment was designed to evaluate corn growth under different depths of corn cob residue that mimic the field storage system used for loose corn cob pile. A randomized complete block design with split-split arrangement with three replications was used. The greenhouse study included five corn cob depths (0, 2.5, 7.6, 15.2, and 22.9 cm) as main treatments, three N fertilizer rates (0, 90, and 180 kg N ha^{-1}), and two lime rates (with and without lime) as a split-split plots.

The greenhouse experiment was conducted at the Agronomy Department Greenhouse facility at Iowa State University. The experiment started in February 8, 2010 and ended in 22nd June, 2010. The soil used for this greenhouse experiment was collected in the fall of 2009, from an irrigated continuous corn site near Emmetsburg. The soil at that site is classified as: Estherville (Sandy, mixed, superactive, mesic Typic Hapludolls). Approximately 2.3 kg of soil was placed in each pot with a 15.2 cm diameter and brought to 1.2-1.3 g/cm^3 soil bulk density. Then each pot was brought to moisture field capacity by saturating the soil with water using capillary flow and then letting it drained naturally. Corn cob was crushed to small pieces (approx. 2.5 cm wide by 5.0 cm long) to simulate the size of corn cob in the field. Five different corn cob rates were used to represent the different amounts of corn cob throughout the pile in the field (Fig. 2.2). Also, the corn cob was soaked in water prior to application on top of each pot to simulate field conditions. A plexiglass collar was constructed on top of each pot to contain and hold different corn cob treatments.

In order to simulate similar weather condition associated with corn cob storage in the field, pots were covered with corn cob and placed outside the greenhouse on February 8th 2010 (Fig. 2.17). On February 22nd 2010, pots were moved to the inside of the greenhouse where they were kept at a constant lighting and at 30 °C during the day time. In order to keep the soil and corn cob moist, water was applied every day to each pot based on water loss from corn cob and soil; water loss was calculated by weighing representative standard pots and cob samples every day before water application. On 12th April 2010, corn cob was removed completely from each pot using the same timeline used for the removal of corn cob pile from sites at Emmetsburg. On 26th April 2010, DeKalb 54-49 VT3 corn seed was planted into each individual pot at a seeding depth of 5 cm. Two seeds were planted to guarantee that at least one plant will emerge in each individual pot. In case of two plants emerging one seedling was removed from the pot.

Each of the corn cob treatments was treated with three N fertilizer rates of 0, 90, and 180 kg N ha^{-1} and two lime rates (with and without lime) . Lime application was adjusted on a pot by pot basis targeting a soil pH between 6.5-6.9 (Sawyer et al., 2002). The pots were randomized in placing them on the bench in the greenhouse to minimize potential light and temperature variability impact on plant growth.

Greenhouse preparation and treatments 2012

A greenhouse experiment was designed to evaluate corn growth under different corn cob extraction concentrations and N fertilizer rates. A randomized complete block design with three replications was used. The greenhouse study included three concentrations of corn cob extractions and three N fertilizer rates (0, 90, and 180 kg N ha^{-1}).

The greenhouse experiment was conducted at the Agronomy Department Greenhouse at Iowa State University. The experiment started on 1st March, 2012 and ended on 9th April, 2012. The soil used for this greenhouse experiment was collected in the fall of 2011, from the AC site at Agronomy Research Farm west of Ames. It is classified as Canisteo silty clay loam (Fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls). Approximately 2.3 kg of soil was placed in each pot with a 15.2 cm diameter and brought to 1.2-1.3 g/cm^3 soil bulk density. Then each pot was brought to moisture field capacity by saturating the soil with water using capillary flow and then letting it drained naturally.

Two seeds of corn (DeKalb 54-49 VT3) were planted to guarantee that at least one plant will emerge in each individual pot, corn seed was planted into each individual pot at a seeding depth of 5 cm. If two plants emerged, one seedling was removed from the pot. Corn cob extraction was done by soaking dry corn cob in deionized water in a large plastic container. Different corn cob to water ratio were used to achieve a desire high and low concentration extractions. The highest concentration for corn cob extraction was defined in this experiment as 1:4 ratio of corn cob mass to deionized water mass. We placed 15 kg of dry corn cob in 60 L of deionized water in a plastic container prior to the start of the greenhouse experiment. The second corn cob extraction concentration was defined as low concentration of 1:6 (10 kg of corn cob in 60 L of water) ratio of corn cob to water. A third treatment was a control treatment, where only deionized water was used. The corn cob was soaked for a week before it was used for irrigating the corn plants.

Treatments were applied using a factorial combination of treatments, where each corn cob extraction was treated with three N fertilizer rates of 0, 90, and 180 kg N ha^{-1}. The application of the treatments to the pots was randomized to minimize light and temperature variability that may affect plant development and growth. For the duration of the study, the pots were watered every day with corn cob extraction of different concentrations and kept at moisture field capacity. In order to keep soil moist, corn cob extract was applied every day to each pot based on water loss from soil; water loss was calculated by weighting representative standard pots every day before corn cob extract application.

Emergence rate index, plant growth and development, and grain yield measurements

Immediately after planting, two rows of 5.3 m long in the center of each plot of different treatments were marked for monitoring corn emergence. Each plot was monitored every day for two consecutive weeks after the first emergence as it is outlined in Erbach (1982). Emergence rate index (ERI) was calculated using the following equation (Erbach 1982):

$$ERI = \sum_{n=first}^{last} \frac{\%n - \%(n-1)}{n} \qquad [1]$$

where n is the number of days after planting, first is the number of days after planting when the first plant emerged, last is the number of days after planting when emergence was completed, %n is the percentage of plants emerged on day n, and %(n-1) is percentage of plants emerged on day n-1. In the same rows used for ERI monitoring, four plants were selected and staked following complete emergence to monitor growth stage development over time. These plants were used for documenting vegetative stages along with extended plant leaf heights measurements (Abendroth, 2011). Plant growth and development measurements were taken every 10 days during growing season and final plant population was collected at the end of the season using the same area. Data collection for ERI, extended plant leaf heights, plant growth and development, and final plant population were taken at specific experimental plots, where at the AC site 5.0 cm corn cob residue treatment and 90 kg N ha^{-1} fertilizer were not included due to time and workload constraints; however, at the ENW site all treatments were collected. Corn grain yield was determined for each plot in both sites. Grain yield at AC sites was harvested using a John Deere 9410 combine, which collected grain and determine grain moisture content from the middle four rows. At the ENW site corn yield was determine by hand harvesting 5.3 m row length of the middle two rows at black layer at each plot (count kernel number, kernel weight, and grain moisture content for determining grain yield). All corn ears were shelled using an Almaco thresher LPR (Almaco, Nevada, IA) to determine the corn yield. For both sites corn grain yield was adjusted to 155 g kg^{-1}.

Above-ground biomass organic C and N concentration measurements

Above-ground biomass from both sites was collected when corn reached black layer at specific experimental plots. At the AC site, 5.0 cm corn cob residue treatment and 90 kg N ha^{-1} fertilizer were not included due to time and workload constraints, while ENW site above-ground biomass was collected for all treatments. Four plants were harvested from each plot by cutting them at ground level and then bundle together. After all plots' above-ground biomass was harvested, plants were transported immediately to the drying facility, where they were dried at 65 °C for 48 hours. After the plants were fully dried, corn cob and grain were separated from stalk and leaves. The stalk and leaves were weighted to determine dry matter weight (Mg ha^{-1}). Plant biomass was grounded to fine powder by using a Wiley Mill 2 grinder (Arthur H Thomas Co, Philadelphia, PA). Corn biomass was analyzed for total carbon and total N by dry combustion using TRUSPEC CN analyzer (LECO Corporation, St. Joseph, MI). Total C and N concentration values are presented in g kg^{-1}.

Greenhouse plant growth and development and above-ground biomass measurements

Greenhouse studies in 2010 and 2012 differ in objectives but their plant measurement procedures are similar. Each pot had a single corn plant which was monitored to document vegetative stages along with extended plant leaf heights measurements, which were determined using a method outline by Abendroth (2011). Plant development and extended plant leaf height measurements were taken every other day during the study. The study was terminated when corn plants reached V6 vegetative growth stage. Then corn plants were removed from pots and cleaned before drying them at 65 °C for 48 hours. After the plants were fully dried, above-ground biomass was weighted to determine dry matter weight (Mg ha^{-1}).

Statistical analysis

Data was analyzed using the statistical analysis procedure PROCMIXED (SAS Institute, 2002). For AC site type of tillage was considered as the main treatment, which was split into different corn cob residue levels and N fertilization rates as split- split-plot by year. Whereas ENW site main treatment was corn cob residue treatments, which was split into different N fertilization rates as split-plot by year. Mean separation was determined using the PDIFF procedure and significance was determined at $p \leq 0.05$, unless otherwise stated.

RESULTS AND DISCCUSION

Loose corn cob experiment (AC site)

Emergence rate index and plant population

In 2011, emergence rate index (ERI) was affected by corn cob residue and tillage system treatments, but no differences were found due to N fertilizer rates ($p=0.6876$ and $p=0.5296$ for 2011 and 2012, respectively), thus an average across N fertilizer was used to summarize ERI for both years (Fig. 2.3). It was observed that, ERI for both tillage systems was similar for control and 2.5 cm corn cob residue; however, the NT system showed greater ERI for removed but lower ERI for 7.5 cm corn cob residue treatment when compared to the CT system. Excessive loose corn cob residue cover on soil surface showed a negative effect on ERI, where on average 2.5 and 7.5 cm of corn cob residue treatments showed a 23% reduction in ERI compared with control and removed corn cob residue treatments. This reduction can be attributed to soil condition associated with poorly-drained soil as the amount of corn cob residue increased. Such conditions if not managed correctly can cause slow growth and development due to low soil temperature (Kaspar et al., 1990; Bollero et al., 1996; Fortin and Pierce, 1991), which often leads to slow plant emergence and N mineralization (Al-Kaisi and Kwaw-Mensah, 2007).

In 2012 corn cob residue treatments of control, removed residue, and 2.5 cm depths with CT show similar ERI with the 7.5 cm corn cob residue treatment having a lower ERI compared to control and removed treatments (Fig. 2.3). However, no differences in ERI were observed between corn cob residue treatments with the NT system. The lack of differences in ERI in 2012 can be attributed to the drought condition, where in the month of May, the AC site received on average 31 mm less rainfall and air temperature was 4 °C higher compared to May 2011 (Fig. 2.1.) Drought conditions can affect the morphological behavior of corn hybrids and reduce seed germination and early seedling growth (Khodarahmpour, 2011). However, the lack of differences in ERI with NT under such drought stress may be moderated by the cover of corn cob residue by conserving soil moisture (Blevins et al., 1983).

Final corn population was mainly affected by tillage system and corn cob residue treatments and no differences were observed due to N fertilization in both years (p=0.6685 and p=0.0809 for 2011 and 2012, respectively), thus an average across N fertilizer was used to summarize final corn population(Fig. 2.4). In 2011, final plant population show no differences across tillage system and corn cob residue treatments with the exception of 7.5 cm corn cob residue treatment with NT, which showed the lowest final plant population when compared to the rest of corn cob residue treatments and tillage systems. Row cleaners' attachments on planter were used during planting of corn for the AC site especially with NT. Also, it was noticed that NT with 7.5 cm corn cob residue treatment was most challenging during planting, thus lower final plant population was observed due to the poor seed-soil contact and shallow seed depth with insufficient moisture for germination (Hunter and Erickson, 1952).

Meanwhile, final corn population for 2012 was highly variable across corn cob residue treatments and tillage systems (Fig. 2.3). Lower final corn population was observed across all corn cob residue treatments under CT compared to NT. Corn cob residue cover with NT system increased soil moisture compared to CT system, leading to reduction of drought stress on plant growth (Cairns et al., 2013).

Vegetative stages and extended leaf plant height

In general vegetative growth stages and extended plant leaf heights showed lower values early in the growing season with corn cob residue treatments for CT and NT in both years. There were no differences in growth stages and extended plant leaf heights due to N fertilizer rates (for growth stages p=0.3351 and p=0.3757 for 2011 and 2012, respectively and for extended plant leaf heights p= 0.1181 and p=0.2130 for 2011 and 2012, respectively), thus an average across N fertilizer was used to summarize 2011 and 2012 (Fig. 2.5 and Fig. 2.6), respectively. Delays in vegetative growth stages and shorter extended plant leaf heights due to corn cob residue treatments, 2.5 cm and 7.5 cm, were observed during the growing season in both years. Generally, the complete removal of corn cob residue improved vegetative growth stages and extended plant leaf heights. Corn cob residue treatments (2.5 cm and 7.5 cm) with both tillage systems caused a delay in the development of vegetative growth stage by 1.25 and 0.75 vegetative growth stage in 2011 and 2012, respectively. However, the final number of leaves per plant was not affected by corn cobs residue treatments for both years. Nevertheless, the extended plant leaf heights were affected by corn cob residue treatments (2.5 cm and 7.5 cm) where on average, plants were 15 cm shorter compared to control and completely removed corn cob residue treatments for CT and NT in both years. Excessive amount of corn cob residue on the soil surface kept soil wet and cold early in the growing season, which may contribute to plant growth delay (Cox et al., 1990 and Bollero et al., 1996).

Above-ground biomass and corn yield

Above-ground biomass results with different corn cob residue, tillage system, and N fertilizer rates are presented in Fig. 2.7. It was observed that 0 kg N ha^{-1} produced lower above-ground biomass with CT and NT at each year. However, a decrease in above-ground biomass as the corn cob residue depths increased was noticeable for NT and CT in 2011. Generally, differences in above-ground biomass between corn cob residue treatments and N fertilizer rates up to 180 kg N ha^{-1} or above for both tillage systems and both years were not different. The observed increase in above-ground biomass with high N fertilizer rates is expected due to the effect of N fertilizer on plant growth by altering leaf area and photosynthetic capacity (Novoa and Loomis, 1981).

Grain yield was mostly affected by corn cob residue treatments and N fertilizer, where no differences caused by tillage system in both years was observed (p=0.1181 and p=0.2130 for 2011 and 2012, respectively), thus an average was used to summarize grain yield across tillage system (Fig. 2.8). Corn cob residue treatments of 2.5, 5.0, and 7.5 cm depth resulted in lower corn yield at 0 and 90 kg N ha^{-1} in 2011; when compared to control and removed corn cob residue treatments. In 2012 the application of 90, 180, and 270 kg N ha^{-1} across all corn cob residue treatments produce greater corn yield when compared to 0 kg N ha^{-1} (Fig. 2.8). In general, the application of N fertilizer improved corn grain yield across all corn cob residue treatments in both years. A significant change in grain yield was observed when N fertilizer rate is increased from 0 to 180 kg N ha^{-1}. These results are in agreement with other studies that have documented that regardless of tillage system, there was no increase in yield in response to additional N fertilizer application above 180 kg N ha^{-1} (Al-Kaisi and Waskom, 2002; Al-Kaisi and Kwaw-Mensah, 2007).

Studies have shown that in soils similar to those in this study, which are high in clay content in the Corn Belt can potentially be affected by high amount of residue on the soil surface. Corn cob residue can potentially slow down soil warming in the spring and reduce plant emergence, N mineralization, and crop growth (Al-Kaisi and Kwaw-Mensah, 2007). Also, it can influence N availability early in the growing season by slowing down soil organic C and N mineralization and subsequent plant N use or accumulation (Al-Kaisi and Licht, 2004; Licht and Al-Kaisi, 2005; Mehdi et al., 1999; Sanju and Singh, 2001) resulting in lower grain yields.

Above-ground biomass and grain organic C and N concentrations

Grain organic C and N concentrations show no differences due to corn cob residue treatments and years ($p=0.2082$ and $p=0.2970$ for C and N, respectively), thus an average across corn cob residue and both years is used in Table 2.1, where tillage system and N fertilizer are shown. In general organic C concentration in corn grain shows no difference across tillage system and N fertilizer rates. However, high N fertilizer rates increased N concentration in corn grain for both tillage systems. Also, N concentrations in grain for CT under 180 and 270 kg N ha^{-1} are higher than in NT for the same N fertilizer rates. Similar results were found by Al-Kaisi and Kwaw-Mensah (2007) and Jantalia and Halvorson (2011), where high N fertilizer rates increased N concentration in grain. The increase in N concentration in corn grain can be attributed to greater N uptake and yield response to higher N fertilizer rates. As expected, high N concentration will lower C:N ratio under high N fertilizer rates in corn grain.

Above-ground biomass organic C and N concentrations were mostly affected by corn cob residue treatments, N fertilizer, and years. No difference was observed due to tillage system (for organic C $p=0.1469$ and $p=0.3889$ for 2011 and 2012, respectively and for N concentrations, $p=0.2340$ and $p=0.3322$ for 2011 and 2012, respectively), thus an average across CT and NT is used to summarize 2011 and 2012 in Table 2.2 and Table 2.3, respectively. According to Al-Kaisi et al., (2005) different tillage systems did not affect organic C and N concentrations in above-ground biomass, which agrees with findings of this study. In 2011generally above-ground biomass organic C and N concentrations are affected by N fertilizer rate, where 180 and 270 kg N ha^{-1} showed higher organic C and N concentrations compared to 0 kg N ha^{-1}across all corn cob residue treatments (Table 2.2).

In 2012, above-ground biomass organic C was affected by N fertilizer rate, however no differences were observed with the exception of 180 and 270 kg N ha^{-1} with 2.5 cm corn cob residue treatment, which showed higher biomass C concentration compared to 0 kg N ha^{-1}. Also, the N fertilizer rate affected N concentrations in above-ground biomass, where 180 and 270 kg N ha^{-1} showed higher biomass N concentration compared to 0 kg N ha^{-1} across all corn cob residue treatments (Table 2.3). High N fertilizer rates increased above-ground biomass N concentrations across corn cob residue treatments in both years. Similar results were found by Jantalia and Halvorson (2011), where increase in N fertilizer rate increased N content in the above-ground biomass.

Above-ground biomass C:N ratios for both years decreased with increasing N fertilizer rates across all corn cob residue treatments. One reason for this low C:N ratio at high N fertilizer rates may be due to luxury N uptake at high N supply leading to high accumulation of N in the corn stalks (Hesterman et al., 1987, Kwaw-Mensah and Al-Kaisi 2006). The values of biomass organic C and N concentrations are in agreement with those reported by Latshaw and Miller (1924). Plant materials with high C:N ratios decompose much slower than those with lower C:N ratio. With a lower C:N ratio, micro-organisms are able to quickly break down plant materials without depleting N from the soil (Burgess et al., 2002; Havlin et al., 2005). Thus appropriate N fertilizer rates need to be used in order to keep a good plant/soil relationship.

Corn cob bale experiment (ENW site)

Emergence rate index and plant population

The ERI and plant population was mainly affected by corn cob residue treatments left on soil surface after bales removal. The N fertilizer did not affect ERI and plant population in both years (for ERI p=0.6798 and p=0.1353 for 2011 and 2012, respectively and for plant population p=

0.4637 and p=0.7377 for 2011 and 2012, respectively), thus an average across N fertilizer was used to summarize corn cob residue treatments after bale storage and removal. Corn cob residue left after removal of bales in 2011 showed lower ERI compared to Control and across all corn cob residue treatment in 2012 (Fig. 2.11.). Lower ERI in 2011 can be attributed to conditions associated with poorly-drained soil as the amount of corn cob residue left after corn cobs bale removal increase. Soil surface cover with corn cob residue if not managed correctly can cause slow plat emergence (Kaspar et al., 1990; Bollero et al., 1996; Fortin and Pierce, 1991), and N mineralization (Al-Kaisi and Kwaw-Mensah, 2007).In 2012, higher ERI was observed across all corn cob residue treatments compared to 2011. This could be due to adequate soil temperature, moisture, and seed-to-soil contact making corn seedling uniform and vigorous. The ENW site was planted on 25th April, 2012, during the months of April and May of 2012 the ENW site received on average 38 mm of rainfall and air temperature was 13°C (Fig. 2.9), which are appropriate environment conditions for a uniform corn seedling emergence.

In general, no differences in plant population were found between corn cob residue treatments in 2011. However, in 2012 left corn cob residue treatment on soil surface showed higher plant population than control and removed residue treatments (Fig. 2.12). Also, it was observed that a higher plant population was planted in 2012 than that in 2011, which affected final plant population results. Areas left with corn cob residue after bale removal had more water available compared to remove and control treatments, due to the soil surface cover with residue conserving soil moisture and providing an advantage during the drought condition (Blevins et al., 1983).

Vegetative stages and extended leaf plant height

Vegetative growth stages and extended plant leaf heights of corn can shed some light on how corn is affected by corn cob bale storage and removal managements. In general vegetative growth stages and extended plant leaf heights were affected by corn cob residue after bale removal and N fertilizer, differently in both years. Therefore, the 2011 and 2012 results are summarized separately in Fig. 2.11 and Fig 2.12, respectively. Similar results were observed between 90 and 180 kg N ha^{-1}, thus 90 kg N ha^{-1} is not showed with the rest of N fertilizer rates. Overall, the vegetative growth stages of corn were not affected by any of the residue treatments after bales removal for either year. Plants with residue left after bale removal and 270 kg N ha^{-1} in 2011 (Fig.2.13 C) show some delay in vegetative growth stages compared to control and removed treatments. . However, the final number of leaves per plant was not affected by corn cobs residue treatments for both years.

In general, the corn cob residue left on the field after bales removal resulted in shorter corn plants compared to the control and removed residue treatments in both years across all N fertilizer rates. Higher N fertilizer rates increased heights of corn plants in both years across all corn cob residues treatments after bale removal. In 2011, plants under left corn cob residue were shorter than control and removed treatments by 10, 10, and 15 cm under 0, 180, and 270 kg N ha^{-1}, respectively (Fig. 2.13 D, E, F); while in 2012 the differences in heights decreased by 10, 0, 3 cm under 0, 180, and 270 kg N ha^{-1}, respectively (Fig. 2.14 D, E, F). The small differences in plant heights in 2012, especially with high N fertilizer rates can be attributed to drought conditions. The extended plant leaf heights differences were present through the growing season in 2011, while in 2012 differences were found only in 0 kg N ha^{-1}. Left corn cob residue treatments resulted in plant growth and development delay early in the season, caused by corn cob residue left on the soil surface especially in wet conditions as in 2011, where soil warm up was delayed (Cox et al., 1990; Bollero et al., 1996).

Above-ground biomass and corn yield

Above-ground biomass is one of the indicators to determine plant performance under different N fertilizer rates and corn cob residue treatments after bales removal. Above-ground biomass under different N fertilizer rates and corn cob residue treatments after bale removal in both years are presented in Fig. 2.15. As expected, 0 kg N ha^{-1} resulted in the lowest above-ground biomass among N fertilizer rates treatments in both years. Also, no differences were observed at each N fertilizer rate across corn cob residue treatments in both years. Thus, above-ground biomass wasn't affected by corn cob residue treatments. However, the observed increase in above-ground biomass with high N fertilizer rates was expected due to the effect of N fertilizer on plant growth and development by altering leaf area and photosynthetic capacity (Novoa and Loomis, 1981).

Grain yield with different N fertilizer rates and corn cob residue treatments after bale removal in both years are presented in Fig. 2.16. Generally, no differences were observed in grain yield between corn cob residue treatments with all N fertilizer rates except at 0 kg N ha^{-1} in both years. The N fertilizer rates above 90 kg N ha^{-1} did not improve grain yield for all corn cob residue treatments, although there was some grain yield increase with the increase in N fertilizer rate in 2011and 2012 (Al-Kaisi and Waskom, 2002). A lower grain yield was observed in 2012, most likely due to drought condition and high air temperature causing water and heat stress, especially during kernel set and grain filling. Heat stress during grain fill can lower grain dry weight, which would reduce corn grain yield (Wilhelm et al., 1999).

Above-ground biomass and grain organic C and N concentrations

Grain organic C was mostly affected by corn cob residue treatments after removal and N fertilizer rate, while N concentration in corn grain showed no differences in effect for any management practices in 2011 and 2012 (Table 2.4 and Table 2.5). In general, organic C concentration in corn grain was not affected by corn cob residue and N fertilizer treatments. However, N fertilizer rates above 90 kg N ha^{-1} caused a slightly increase in organic C concentration across corn cob residue treatments with the exception of control for corn grain in 2011, but no differences were found in 2012. Also, N concentration in corn grain increased with the increase in N application of 90 kg N ha^{-1} or above, but no changes were observed.

Averages of two years of above-ground biomass organic C and N concentrations are summarized in Table 2.6 due to no significant differences between years (p=0.0851 and p=0.6703 for organic C and N concentration, respectively). Above-ground biomass C concentration was not affected by management practices including N fertilizer and corn cob residue treatments. However, above-ground biomass N concentration was affected by N fertilizer rates, where greater N accumulation in above-ground biomass associated with N fertilizer rate increase was observed. In general, the 270 kg N ha^{-1} increased N concentration in above-ground biomass compared to the rest of N fertilizer rates across all corn cob residue treatments. This may be attributed to the luxury N uptake by the plant at high N fertilizer rates (Kwaw-Mensah and Al-Kaisi, 2006)

Above-ground biomass C:N ratios decreased with increasing N fertilizer rates across all corn cob residue treatments. One reason for this lower C:N ratio at high N fertilizer rate may be due to luxury N uptake at high N supply and high accumulation of N in the corn stalks (Hesterman et al., 1987; Kwaw-Mensah and Al-Kaisi 2006). The values of organic C and N concentrations are in agreement with those by Latshaw and Miller (1924). The C:N ratio affects plant materials decomposition, where high C:N ratio lead to slow decomposition by micro-organisms as compared with low C:N ratio, where more energy available for micro-organisms to quickly break down plant materials without depleting nitrogen from the soil system (Burgess et al., 2002; Havlin et al., 2005).

Greenhouse experiment in 2010

Vegetative growth stages and extended plant leaf height

Vegetative growth stages were not affected by N fertilizer rate and corn cob residue treatments in the greenhouse experiment (Fig. 2.18). Similar results were observed in the field experiment, where no differences were found due to complete removal of corn cobs residue and N fertilizer rates. In general, the extended plant leaf heights were shorter for 15.2 and 22.9 cm corn cob residue treatments with 0 kg N ha^{-1}. Also, plants in pots that were treated with different depths of corn cob residue were shorter than those grown in control treatments with 90 and 180 kg N ha^{-1}. On average, there was a decrease in plant height due to corn cob residue (15.2 and 22.9 cm corn cob residue depth treatments) as compared to 2.5-7.6 cm corn residue depths treatments across all N fertilizer rates. This is may be due to removal of corn cob residue before corn planting, which improves soil condition by evaporating any excess water and increase soil temperature (Cox et al., 1990; Bollero et al., 1996).

Above-ground biomass

A comparison of corn cob residue effect and N fertilizer rates on above-ground biomass is presented in Fig. 2.19. Comparing above-ground biomass at each N fertilizer rate and corn cob residue treatment and their interaction in greenhouse experiment can highlight treatments effects under control environment. Above-ground biomass decreased as the amount of corn cob residue depths increased when no N fertilizer was applied, but no differences were observed as the N fertilizer rate increased. The increase in N fertilizer rate led to an increase in above-ground biomass, which is expected due to the effect of N fertilizer on plant growth by altering leaf area and photosynthetic capacity (Novoa and Loomis, 1981).

Greenhouse experiment in 2012

Vegetative growth stages and extended plant leaf height

Vegetative growth stages and extended plant leaf heights were measured in the greenhouse, in order to monitor the progression of plant growth as irrigated with different corn cob extraction ratio and N fertilizer rates treatments (Fig. 2.20). The vegetative growth stages show no differences due to watering with different corn cob extraction ratio in early growth stages across all N fertilizer rates. However, 25 days after planting differences in plant development were observed with 90 and 180 kg N ha^{-1} for control and 1:6 extraction ratio, which showed a faster development than plants under 1:4 extraction ratio . Also, the extended plant leaf heights show decrease at 90 kg N ha^{-1} rate when plants watered with 1:4 extraction ratio compared to control and 1:6 extraction ratios. In general, plants watered with corn cob residue extraction show no difference in extended plant leaf heights with 0 and 180 kg N ha^{-1} rates. According to Martin et al (1990), corn residue extracts can be extremely detrimental for corn seedling, growth, and development.

Above-ground and root biomass

Above-ground biomass for corn cob residue extractions and N fertilizer rates treatments is presented in Fig. 2.21. The most noticeable effect on above-ground biomass was at 0 kg N ha^{-1}, where above-ground biomass was lower compared to 90 and 180 kg N ha^{-1} treatments across all corn cob extraction ratios. The increase in N fertilizer rate from 90 to 180 kg N ha^{-1} showed no differences in above-ground biomass in this experiment. The decrease in above-ground biomass with 0 kg N ha^{-1} appeared to be due to an N fertilizer effect, since there is no change in above-ground biomass across corn cob extraction ratios.

CONCLUSIONS

After two years of loose corn cob residue and bales under different management practices, the following are conclusions and potential recommendations for both studies of loose corn cob residue (AC site) and corn cob bales (ENW site).

Loose corn cob study experiment (AC site)

Plant growth and development, ERI, extended plant leaf heights, and plant population were negatively impacted by the depths of loose corn cob residue left on soil surface; while control (no corn cob residue applied or removed) and residue removed (7.5 cm applied in the fall and completely removed early spring) treatments showed similar results. Also, above-ground biomass and grain yield were slightly affected by the depths of loose corn cob residue left on soil surface. The decrease in above-ground biomass and grain yield were not significant as compared with control and removed treatments. It was also observed that adequate N fertilizer rate at 180 kg N ha^{-1} (agronomic N rate) or above minimized the effect of loose corn cob residue on above-ground biomass and grain yield, but tillage was not a significant factor in correcting the effect of left corn cob residue on the soil surface after piles removal. Above-ground biomass and grain organic C and N concentrations were mostly affected by the increase of N fertilizer rate, but they were not by other management practice such tillage. Although N concentration tends to increase as higher N fertilizer rate was applied. The findings show that the most mitigating practices in reducing corn cob residue effects on plant growth and development and corn yield were adequate N availability using agronomic N fertilizer rate, especially with continuous corn and efficient removal of corn cob from the field. Nitrogen immobilization is one of the main effects in limiting yield and biomass production. Therefore, a balance approach of adequate N fertilizer rates and timing along with tillage and cleaning loose corn cob residue are essential management practices to mitigate such effect.

Corn cob bales experiment (ENW site)

Plant growth and development were not impacted by bales or the presence of corn cob residue left after bales removal from the site. In general, ERI, extended plant leaf heights, plant population, vegetative growth stages, above-ground biomass, and grain yield for clean and left corn cob residue treatments were slightly lower than control treatments. However, no differences were observed for corn cob residue treatments after bales removal. In general, organic C and N concentrations of the above-ground biomass and grain showed no changes with corn cobs reside treatments after bales removal. Adequate N fertilizer rate application and timing of bales removal are essential to mitigate any possible detrimental effects. Also, adequate agronomic N fertilizer rate (180 kg N ha^{-1}) or above, especially with residue left on soil surface after bales removal can mitigate possible effects associated with N-immobilization and slow organic N mineralization due to low soil temperature. Therefore, cleaning corn cob residue is essential to avoid yield reduction due to N deficiency.

Greenhouse experiment

Findings from the greenhouse study confirmed field studies that N fertilizer rates application can mitigate the residual effect of corn cob residue after removal, where N fertilizer rates of 180 kg N ha^{-1} or a higher rate led to improvement of plant growth and above-ground biomass. The consistency between greenhouse and field studies findings is essential in determining potential effects of corn cob residue storage, removal methods, and designing future studies to address some remaining questions. Results of evaluating plant growth and development using extracted organic compounds from corn cob residue had negative effects on vegetative growth stages and above-ground biomass at 90 and 180 kg N ha^{-1} for 1:4 ratio leachate extraction compared to control and 1:6 ratio leachate extractions. Further investigation is needed to understand the effects of corn cob residue leachate on soil-plant relationships.

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Table 2.1. Grain organic C and N concentration (both years average) under tillage system and N fertilizer rates at the Ames Central site (AC).

		Grain		
Tillage System	N Fertilizer	C concentration	N concentration	C:N
	kg N ha^{-1}	----------g kg^{-1}----------		
CT	0	445ab	12d	37a
CT	180	434b	14ab	30d
CT	270	468a	15a	32cd
NT	0	444ab	12d	37a
NT	180	448ab	13c	34b
NT	270	448ab	14bc	33bc

*Means with the same letter within each column are not significantly different at $p \leq 0.05$.
CT is conventional tillage; NT is no-till; C is total carbon; N is total nitrogen.

Table 2.2. Plant organic C and N concentration for 2011 under corn cob residue and N fertilizer rates at the Ames Central site (AC).

		Above-ground biomass 2011		
Corn Cob Residue	N Fertilizer	C concentration	N concentration	C:N
	kg N ha^{-1}	----------g kg^{-1}----------		
Control	0	435cd	9d	50a
Control	180	447ab	10cd	46abcd
Control	270	444ab	11bc	42cde
Removed	0	434d	9d	48a
Removed	180	444ab	11ab	40e
Removed	270	445ab	11ab	40e
2.5 cm	0	434d	9d	48ab
2.5 cm	180	450a	9cd	48ab
2.5 cm	270	444ab	11ab	41de
7.5 cm	0	435cd	9d	47abc
7.5 cm	180	442bc	10bc	43bcde
7.5 cm	270	443ab	12a	38e

*Means with the same letter within each column are not significantly different at $p \leq 0.05$.
Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.

Table 2.3. Plant organic C and N concentration for 2012 under corn cob residue and N fertilizer rates at the Ames Central site (AC).

		Above-ground biomass 2012		
Corn Cob Residue	N Fertilizer	C concentration	N concentration	C:N
	kg N ha^{-1}	----------g kg^{-1}----------		
Control	0	446cd	8b	53a
Control	180	448bcd	10a	46b
Control	270	444d	10a	42b
Removed	0	447bcd	8b	53a
Removed	180	445cd	10a	44b
Removed	270	450abcd	10a	44b
2.5 cm	0	447cd	8b	54a
2.5 cm	180	456a	10a	46b
2.5 cm	270	454ab	10a	44b
7.5 cm	0	448bcd	8b	55a
7.5 cm	180	450abcd	10a	44b
7.5 cm	270	450abc	10a	44b

*Means with the same letter within each column are not significantly different at $p \leq 0.05$
Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.

Table 2.4. Grain organic C and N concentration for 2011 under corn cob residue and N fertilizer rates at the Emmetsburg Northwest site (ENW).

		Grain 2011		
Corn Cob Residue	N Fertilizer	C concentration	N concentration	C:N
	kg N ha^{-1}	----------g kg^{-1}----------		
Control	0	445bcd	12b	36a
Control	90	440e	13b	34ab
Control	180	446bcd	13ab	34ab
Control	270	448ab	14ab	32ab
Removed	0	442de	12b	36a
Removed	90	446bcd	13ab	34ab
Removed	180	445bcd	13ab	34ab
Removed	270	452a	13ab	35ab
Left	0	443cde	12b	37a
Left	90	448ab	17a	30b
Left	180	446bc	12b	36a
Left	270	446bc	14ab	33ab

*Means with the same letter within each column are not significantly different at $p \leq 0.05$.
Control is no bales were placed on plot
Removed is corn cob and other residue were completely removed from each plot after bale storage
Left is corn cob residue on soil surface after bale removal as results of bales breakdown during the removal process if any

Table 2.5. Grain organic C and N concentration for 2012 under corn cob residue and N fertilizer rates at the Emmetsburg Northwest site (ENW).

		Grain 2012		
Corn Cob Residue	N Fertilizer	C concentration	N concentration	C:N
	kg N ha^{-1}	----------g kg^{-1}----------		
Control	0	432a	13cd	33ab
Control	90	425a	15abc	28cdef
Control	180	426a	15abc	28def
Control	270	431a	14bcd	32abcd
Removed	0	430a	13cd	33abc
Removed	90	435a	14bcd	31bcde
Removed	180	427a	14abc	30bcdef
Removed	270	431a	15abc	28cdef
Left	0	428a	12d	36a
Left	90	417a	14abc	29bcdef
Left	180	427a	16a	26f
Left	270	416a	15ab	27ef

*Means with the same letter within each column are not significantly different at $p \leq 0.05$.
Control is no bales were placed on plot.
Removed is corn cob and other residue were completely removed from each plot after bale storage.
Left is corn cob residue on soil surface after bale removal as results of bales breakdown during the removal process if any.

Table 2.6. Plant organic C and N concentration (both years average) under corn cob residue and N fertilizer rates at the Emmetsburg Northwest site (ENW).

		Above-ground biomass		
Corn Cob Residue	N Fertilizer	C concentration	N concentration	C:N
	kg N ha^{-1}	----------g kg^{-1}----------		
Control	0	442a	9cd	50a
Control	90	446a	9cd	49a
Control	180	449a	10abc	44bc
Control	270	447a	11ab	41cd
Removed	0	439a	9cd	49a
Removed	90	446a	9cd	49a
Removed	180	444a	10abc	43c
Removed	270	444a	12a	38d
Left	0	371a	8d	48ab
Left	90	447a	9cd	50a
Left	180	450a	9bcd	48a
Left	270	44a	11a	41cd

*Means with the same letter within each column are not significantly different at $p \leq 0.5$.
Control is no bales were placed on plot
Removed is corn cob and other residue were completely removed from each plot after bale storage
Left is corn cob residue on soil surface after bale removal as results of bales breakdown during the removal process if any.

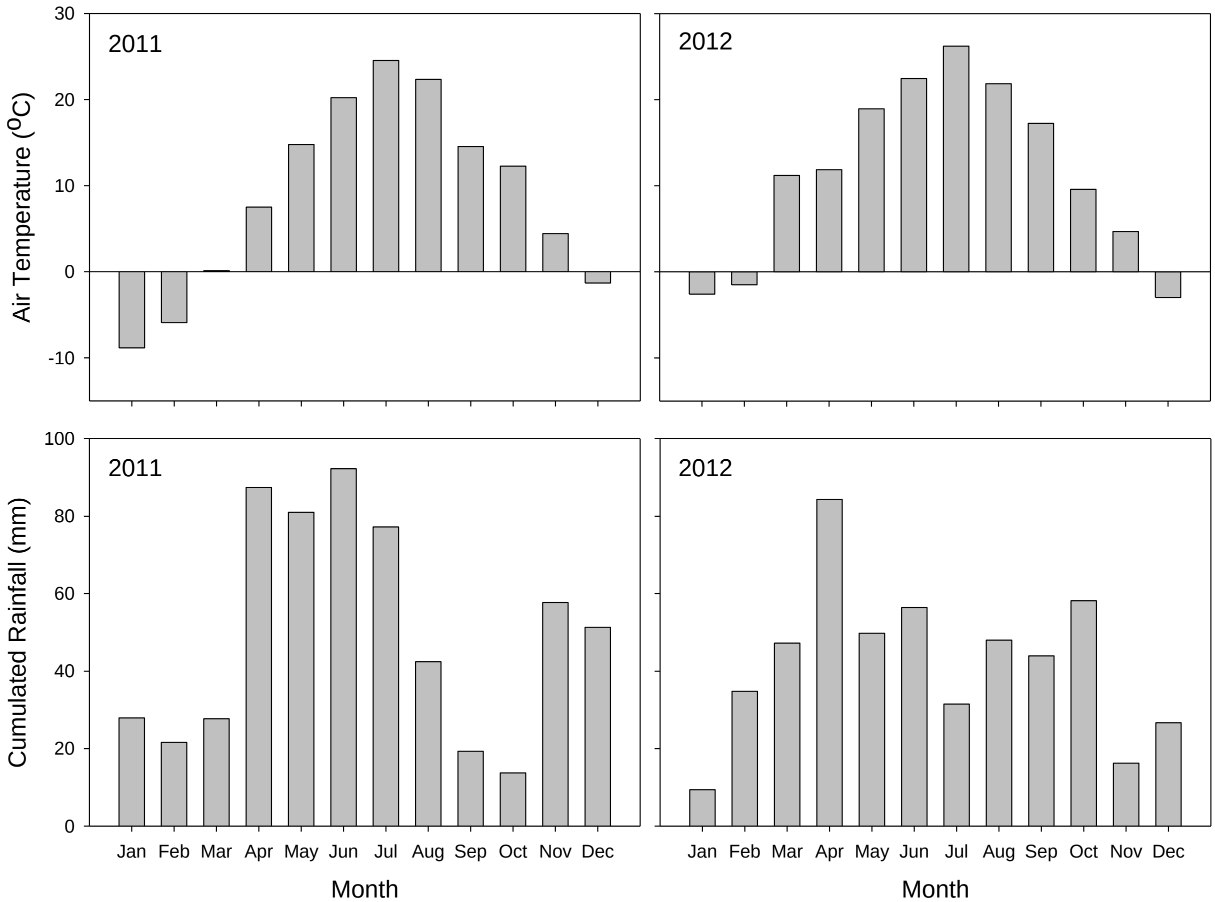

Figure 2.1. Average monthly air temperature and rainfall by years (2011 and 2012) in Ames central site (AC).

Figure 2.2. Corn cob pile and corn cob residue effect on plant growth in 2009-2010 at Emmetsburg, IA.

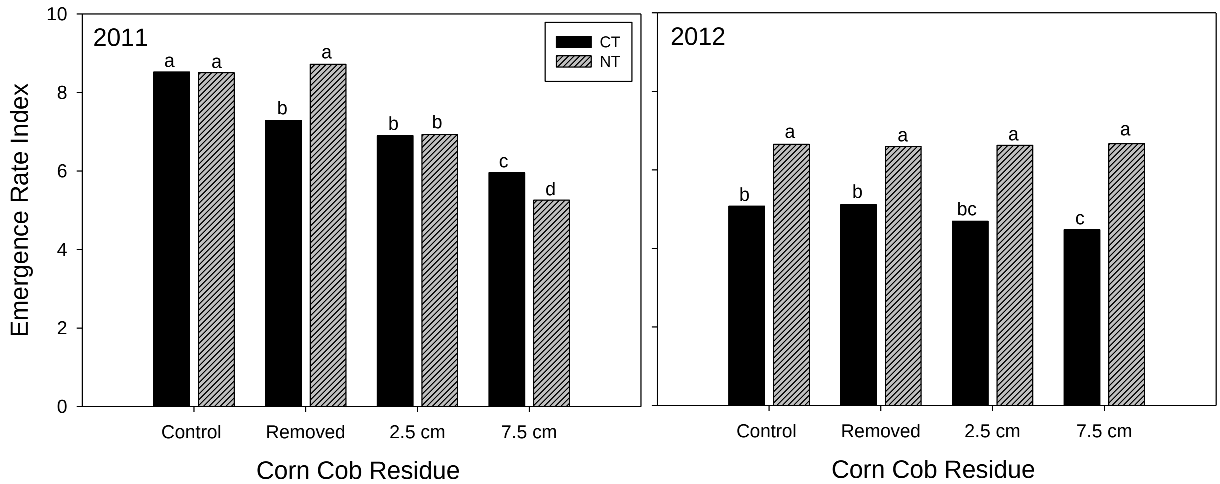

Figure 2.3. Corn cob residue effects on emergence rate index across nitrogen fertilizer rates by tillage system for 2011 and 2012 in the Ames Central site (AC). Means with the same letter across tillage system, within each year are not significantly different at $p \leq 0.05$.

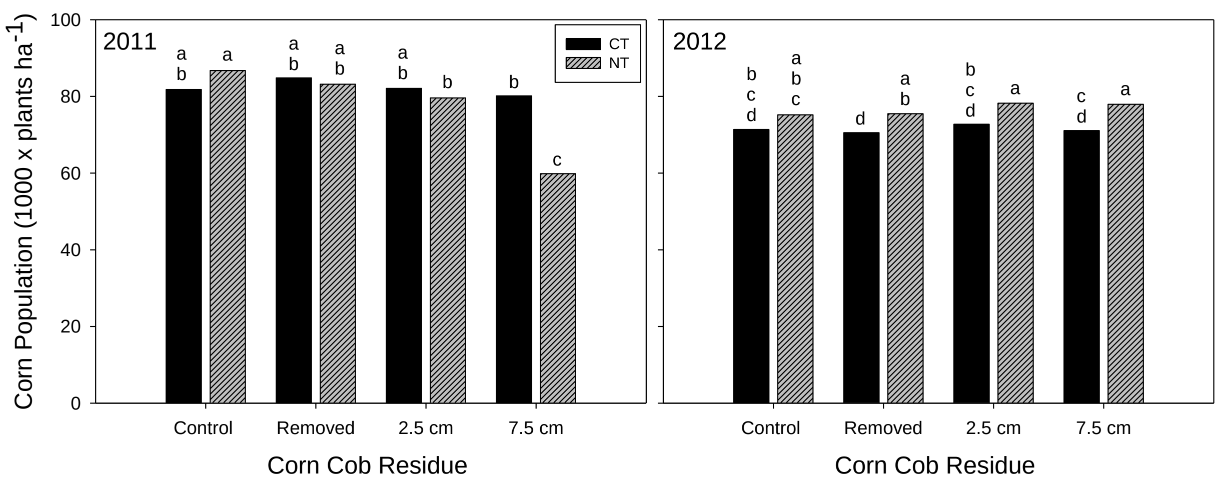

Figure 2.4. Corn cob residue effects on final plant population across nitrogen fertilizer rates by tillage system for 2011 and 2012 in the Ames Central site (AC). Means with the same letter across tillage system, within each year are not significantly different at $p \leq 0.05$.

Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.
CT is conventional tillage; NT is no-till.

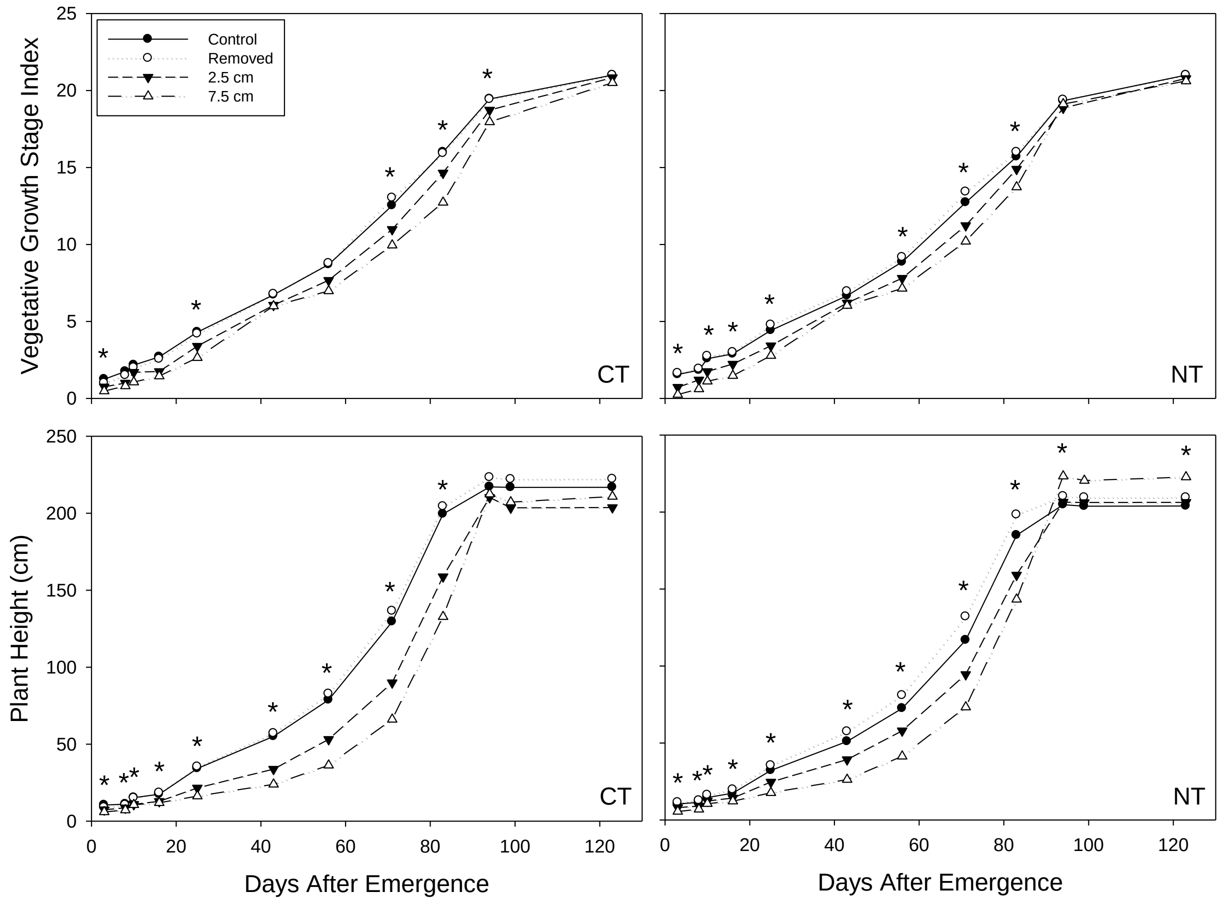

Figure 2.5. Corn cob residue effect on vegetative growth stages and plant heights across nitrogen fertilizer rates by tillage system for 2011 in Ames Central site (AC). A significant difference across corn cob residue treatments within each day of emergence and tillage system is noted with an asterisk (*) at $p \leq 0.05$.

Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.
CT is conventional tillage; NT is no-till.

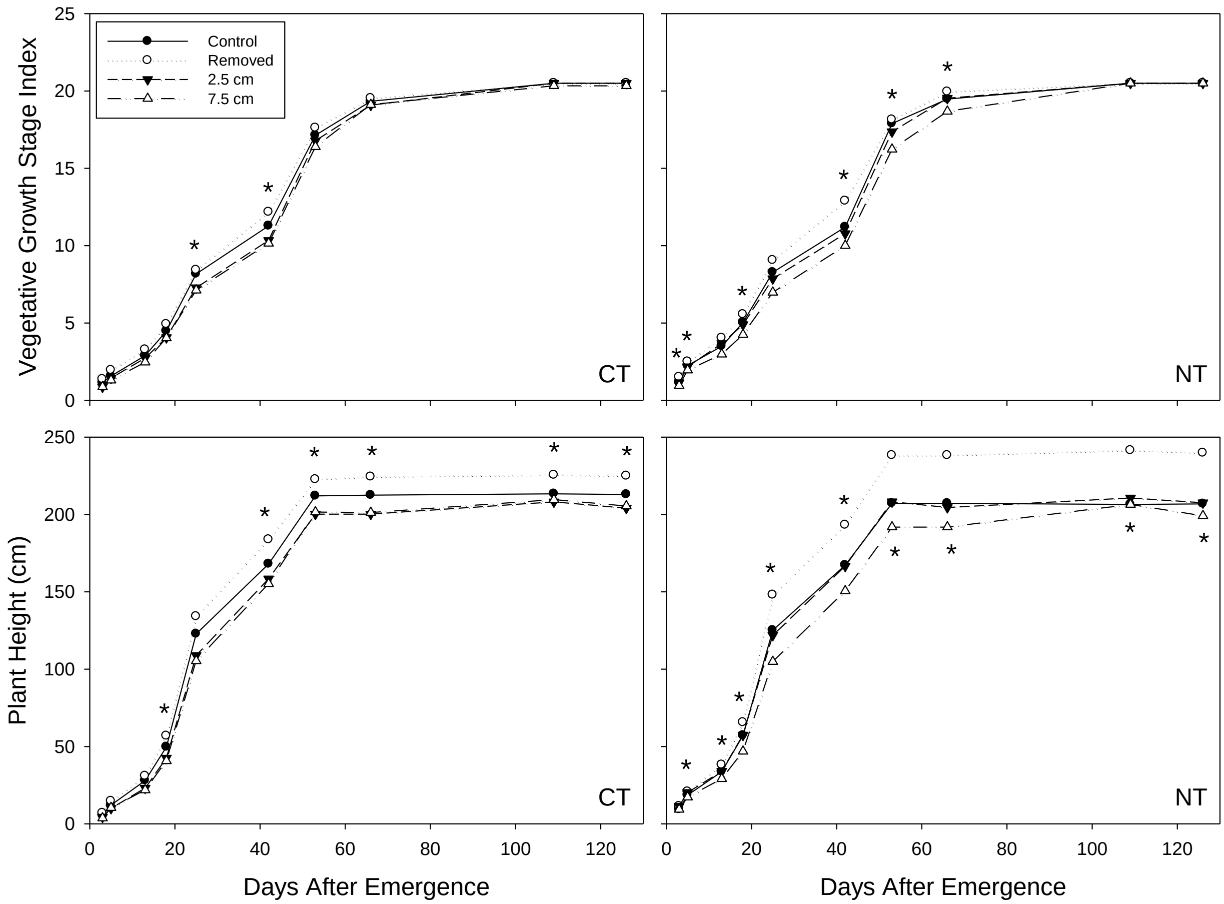

Figure 2.6. Corn cob residue effect on vegetative growth stages and plant heights across nitrogen fertilizer rates by tillage system for 2012 in Ames Central site (AC). A significant difference across corn cob residue treatments within each day of emergence and tillage system is noted with an asterisk (*) at $p \leq 0.05$.

Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.
CT is conventional tillage; NT is no-till.

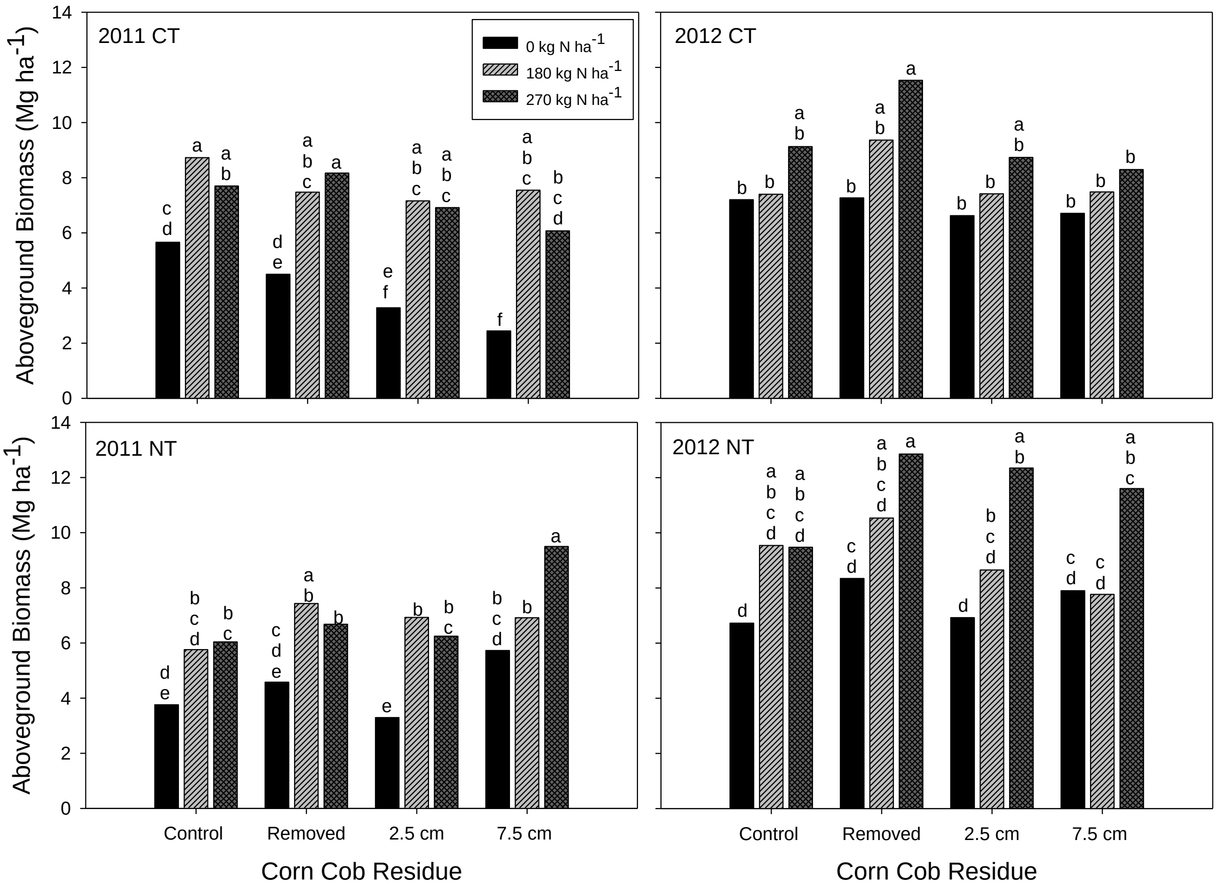

Figure 2.7. Corn cob residue effects on above ground biomass by nitrogen fertilizer rates, tillage system, and years in Ames Central site (AC). Means with the same letter across nitrogen fertilizer rates, within tillage system and each year are not significantly different at $p \leq 0.05$.

Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.
CT is conventional tillage; NT is no-till.

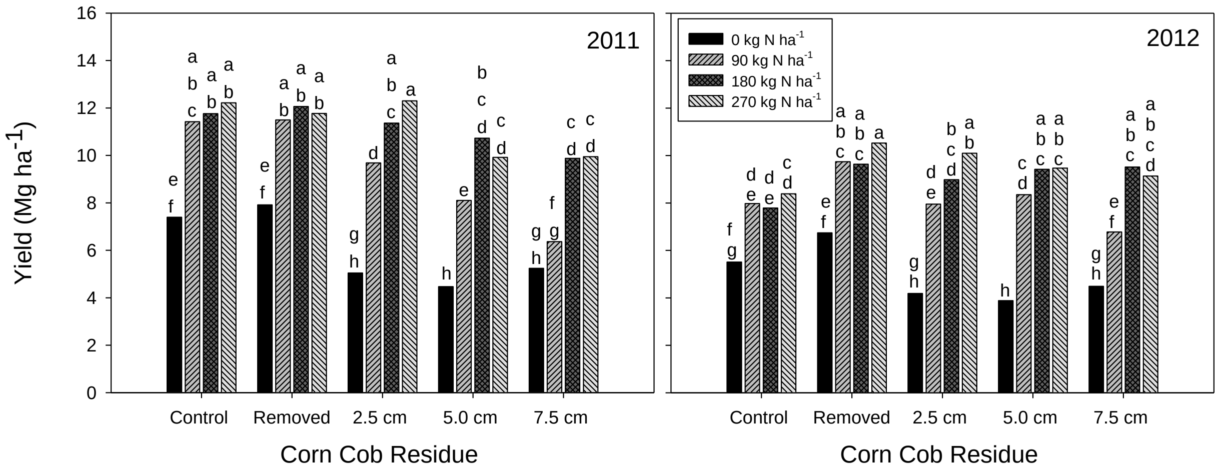

Figure 2.8. Corn cob residue effects on grain yield across tillage system by nitrogen fertilizer rates for 2011 and 2012 in Ames Central site (AC). Means with the same letter across corn cob residue and nitrogen fertilizer rates, within each year are not significantly different at p ≤ 0.05.

Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.

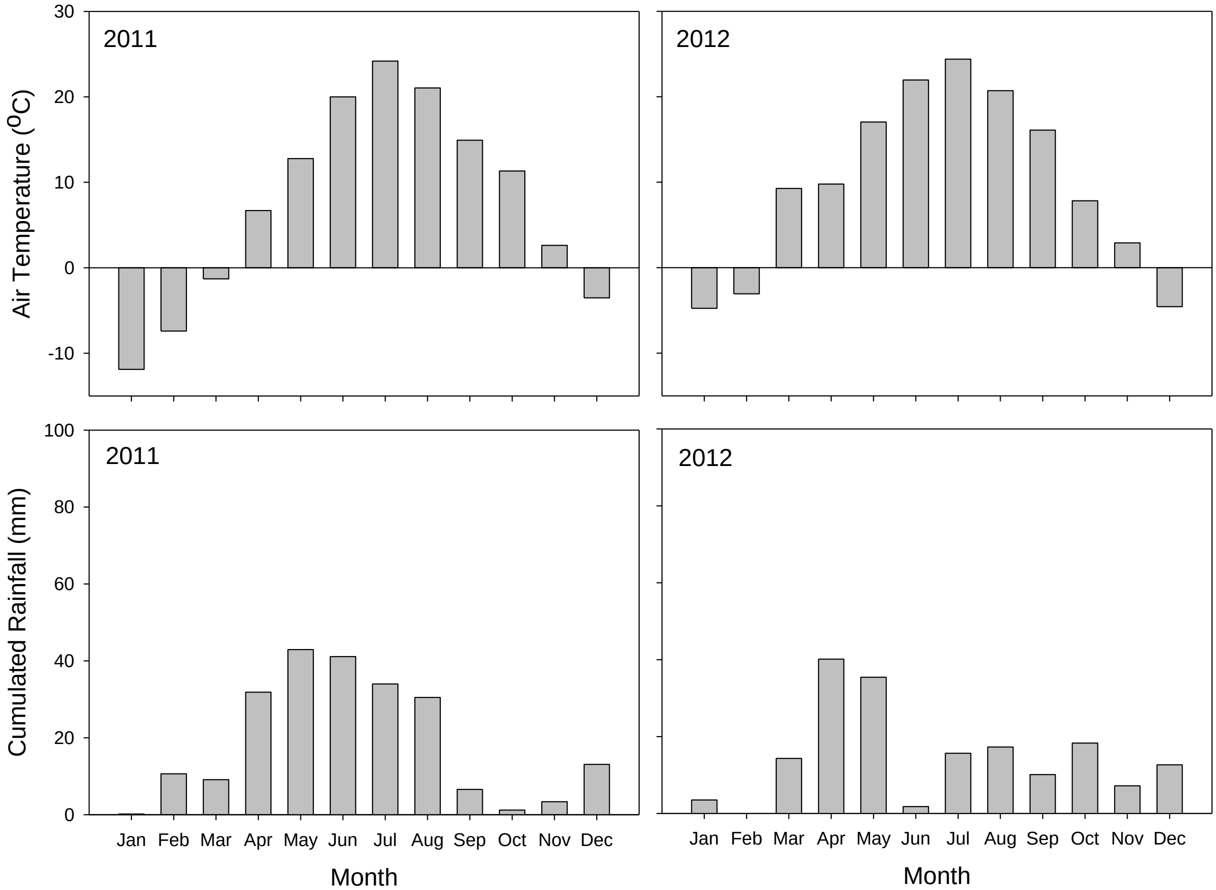

Figure 2.9. Average monthly air temperature and rainfall by years (2011 and 2012) in Emmetsburg Northwest site (ENW).

Figure 2.10. Corn cob bales placement after harvest in 2011 at Emmetsburg Northwest site (ENW).

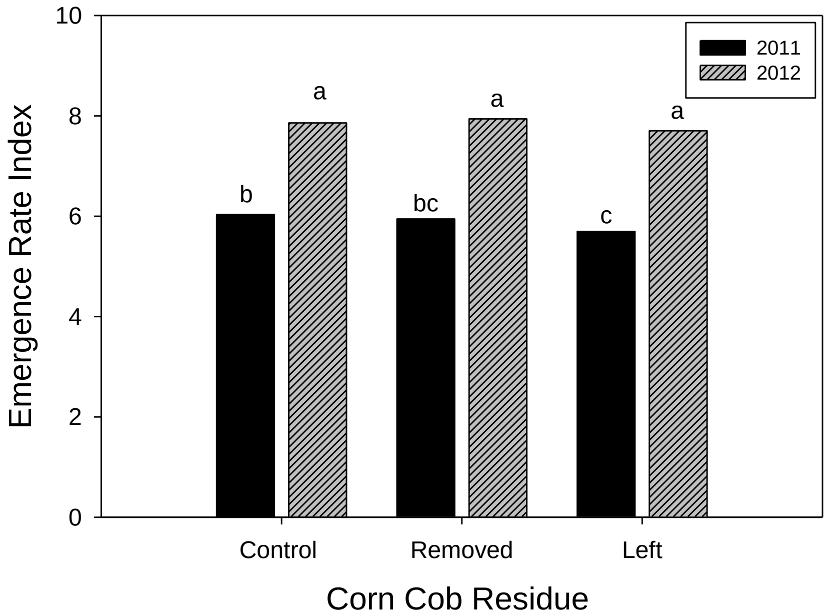

Figure 2.11. Corn cob residue effects on emergence rate index across nitrogen fertilizer rates for 2011 and 2012 in Emmetsburg Northwest site (ENW). Means with the same letter across corn cob residue and year are not significantly different at $p \leq 0.05$.

Control is treatment where no bales were placed on plot
Removed is corn cob and other residue were completely removed from each plot after bale storage
Left is corn cob residue on soil surface after bale removal as results of bales breakdown during the removal process if any.

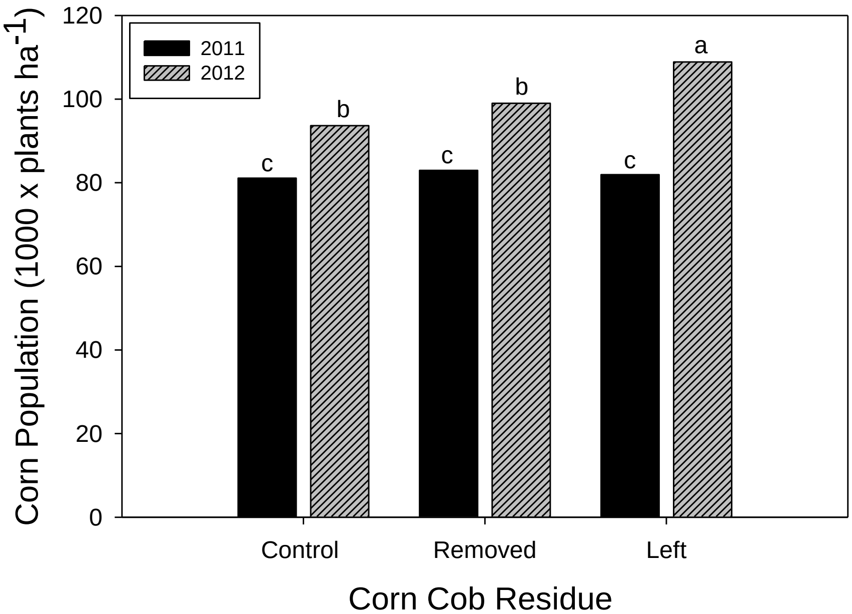

Figure 2.12. Corn cob residue effects on final plant population across nitrogen fertilizer rates for 2011 and 2012 in Emmetsburg Northwest site (ENW). Means with the same letter across corn cob residue and year are not significantly different at $p \leq 0.05$.

Control is treatment where no bales were placed on plot
Removed is corn cob and other residue were completely removed from each plot after bale storage
Left is corn cob residue on soil surface after bale removal as results of bales breakdown during the removal process if any.

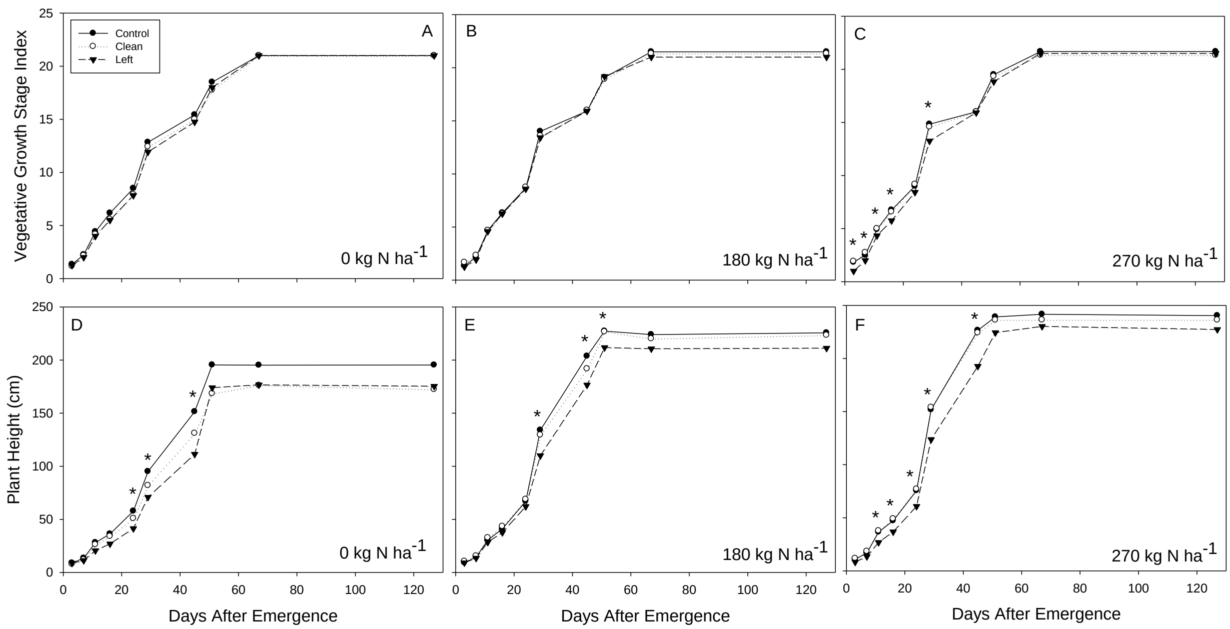

Figure 2.13. Corn cob residue effect on vegetative growth stages and plant heights by nitrogen fertilizer rates for 2011 in Emmetsburg Northwest site (ENW). A significant difference across corn cob residue treatments within each day of emergence and nitrogen fertilizer rate is noted with an asterisk (*) at $p \leq 0.05$.

Control is a treatment where no bales were placed on plot
Removed is corn cob and other residue were completely removed from each plot after bale storage
Left is corn cob residue on soil surface after bale removal as results of bales breakdown during the removal process if any.

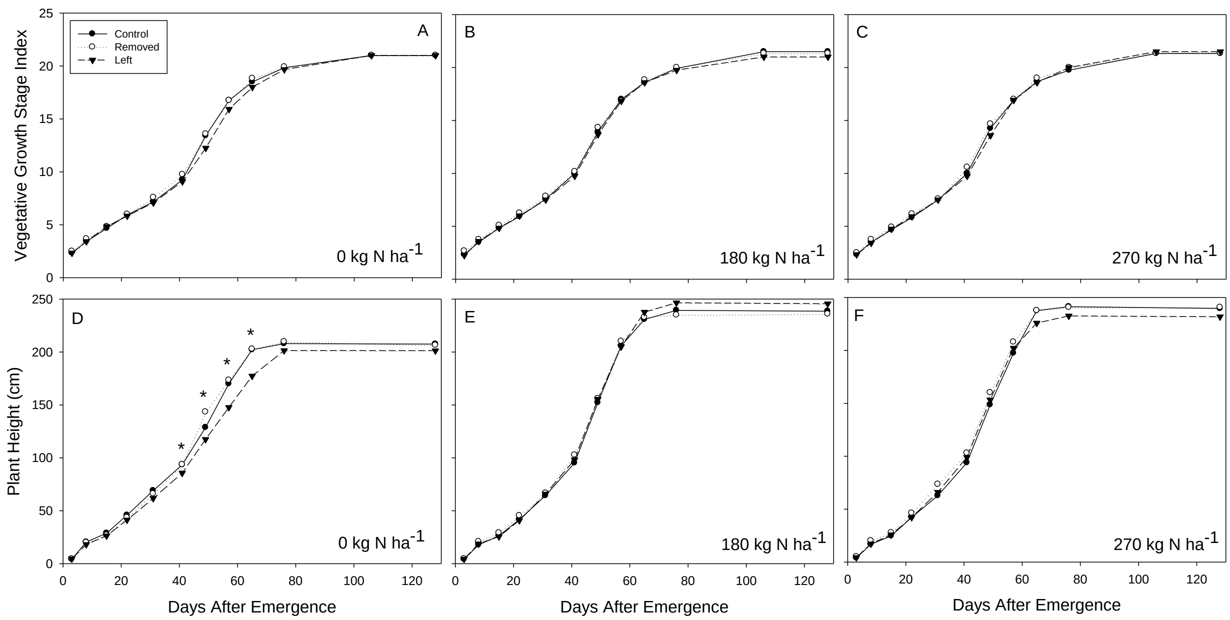

Figure 2.14. Corn cob residue effect on vegetative growth stages and plant heights by nitrogen fertilizer rates for 2012 in Emmetsburg Northwest site (ENW). A significant difference across corn cob residue treatments within each day of emergence and nitrogen fertilizer rate is noted with an asterisk (*) at $p \leq 0.05$.

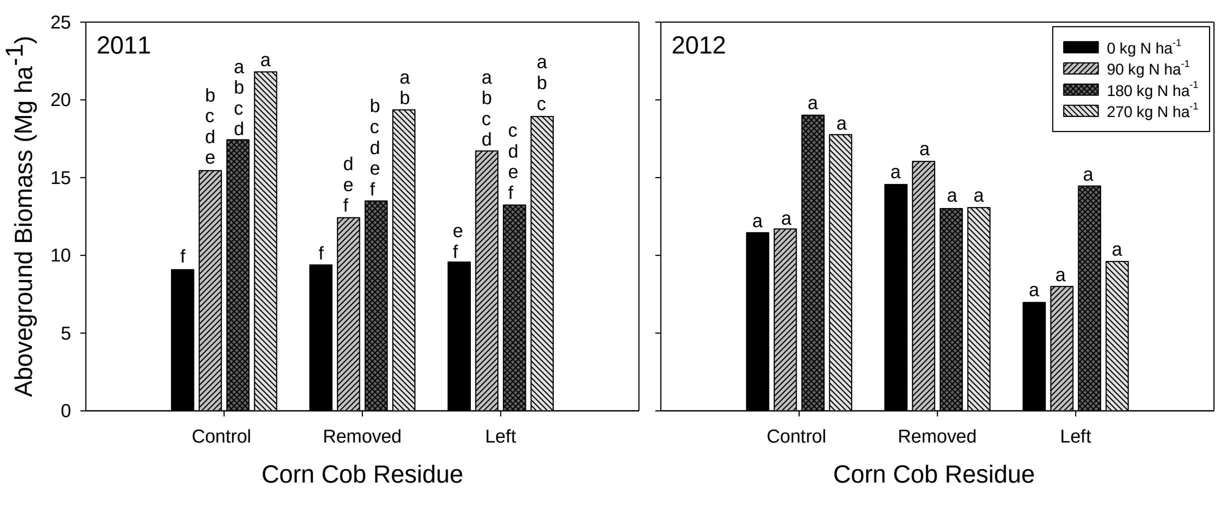

Figure 2.15. Corn cob residue effects on above-ground biomass by nitrogen fertilizer rates for 2011 and 2012 in Emmetsburg Northwest site (ENW). Means with the same letter across nitrogen fertilizer rates, within each year are not significantly different at $p \leq 0.05$.

Control is treatment where no bales were placed on plot
Removed is corn cob and other residue were completely removed from each plot after bale storage
Left is corn cob residue on soil surface after bale removal as results of bales breakdown during the removal process if any.

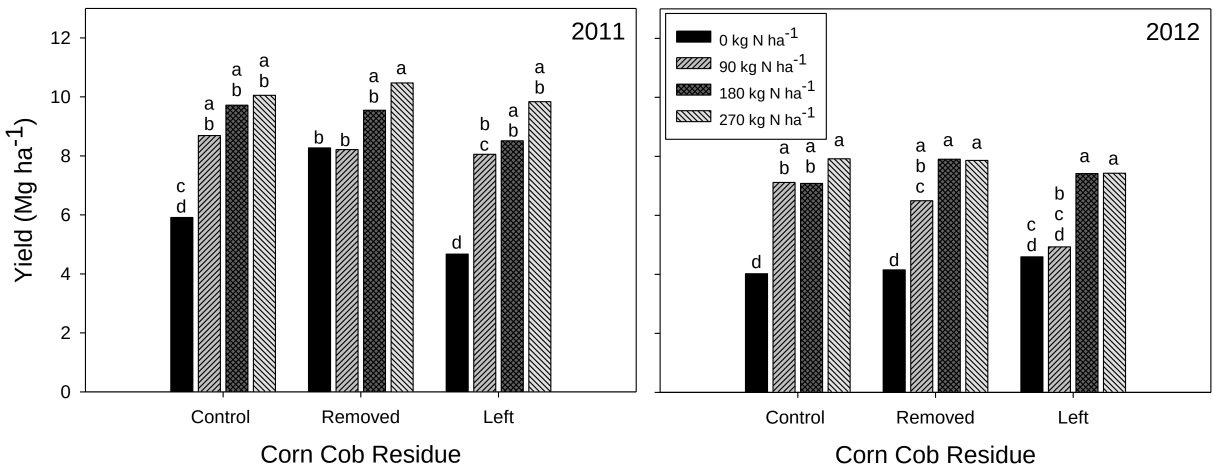

Figure 2.16. Corn cob residue effects on grain yield by nitrogen fertilizer rates for 2011 and 2012 in Emmetsburg Northwest site (ENW). Means with the same letter across nitrogen fertilizer rates, within each year are not significantly different at $p \leq 0.05$.

Control is a treatment where no bales were placed on plot
Removed is corn cob and other residue were completely removed from each plot after bale storage
Left is corn cob residue on soil surface after bale removal as results of bales breakdown during the removal process if any.

Figure 2.17. Greenhouse study 2010 pots covered with corn cob residue and snow next to the Agronomy Department Greenhouse facility at Iowa State University.

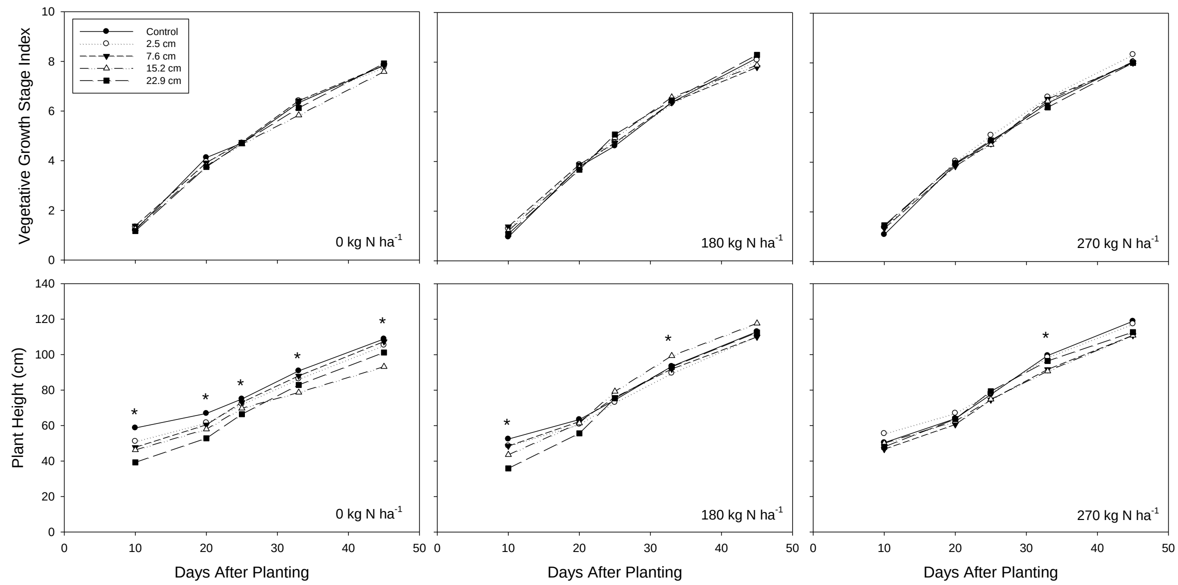

Figure 2.18. Corn cob residue effect on vegetative growth stages and plant heights by nitrogen fertilizer rates for greenhouse experiment 2010. A significant difference across corn cob residue treatments within each day of emergence and nitrogen fertilizer rate is noted with an asterisk (*) at $p \leq 0.05$.

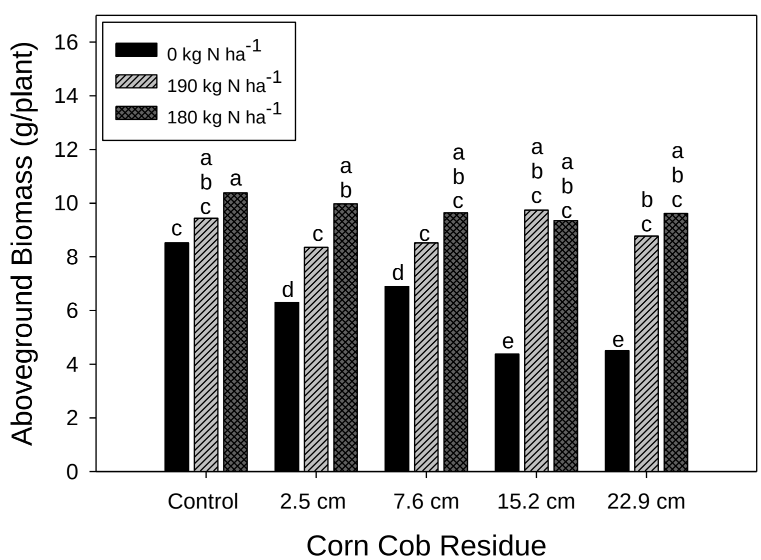

Figure 2.19. Corn cob residue effects on above-ground biomass by nitrogen fertilizer rates for greenhouse experiment 2010. Means with the same letter across nitrogen fertilizer rates, within each year are not significantly different at $p \leq 0.05$.

Control no is corn cob residue applied.
2.5 cm is corn cob residue depth.
7.6 cm is corn cob residue depth.
15.2 cm is corn cob residue depth.
22.9 cm is corn cob residue depth.

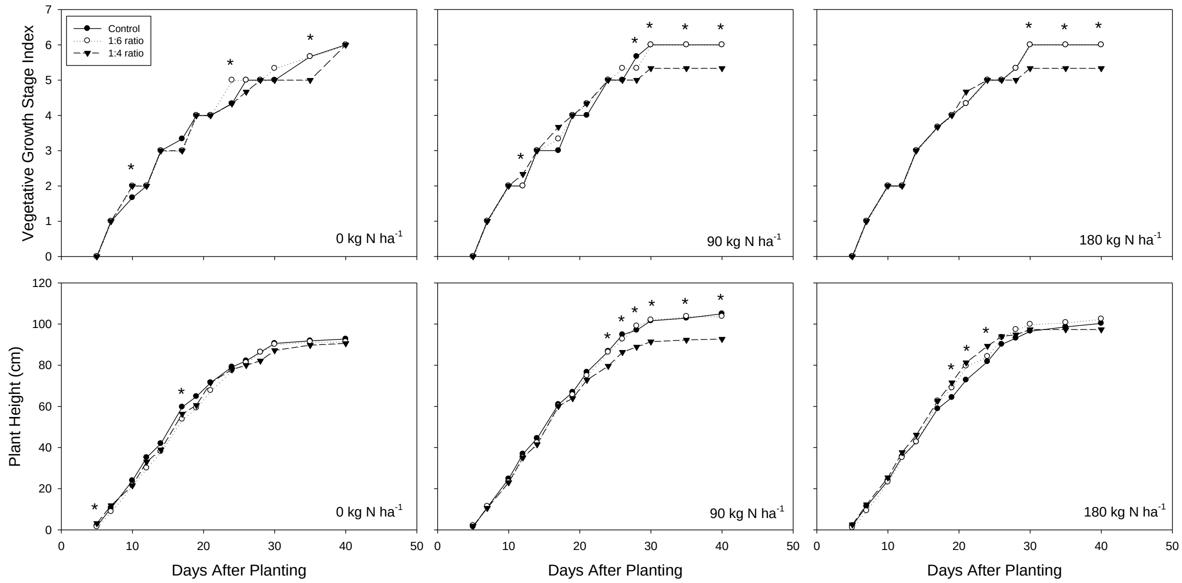

Figure 2.20. Corn cob residue leaching effect on vegetative growth stages and plant heights by nitrogen fertilizer rates for greenhouse experiment 2012. A significant difference across corn cob residue treatments within each day of emergence and nitrogen fertilizer rate is noted with an asterisk (*) at $p \leq 0.05$.

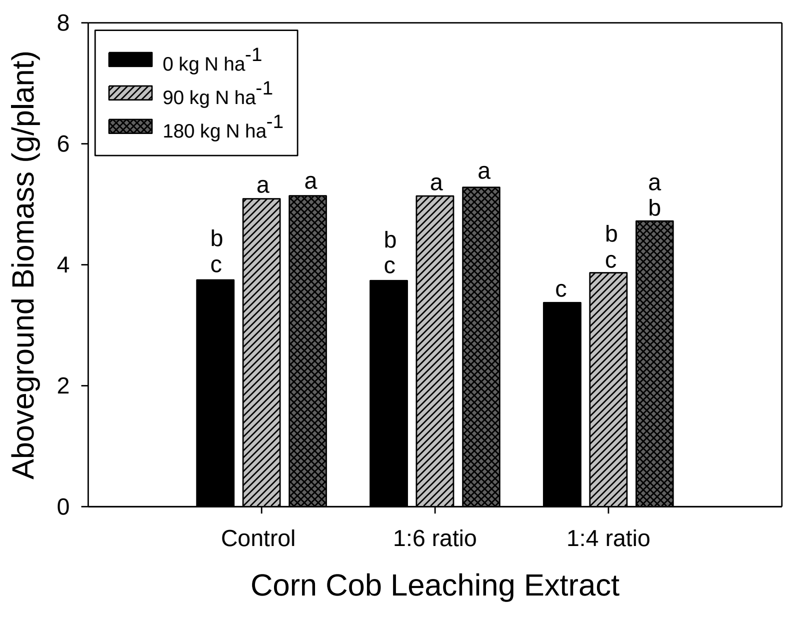

Figure 2.21. Corn cob residue leaching effects on above-ground biomass by N fertilizer rates for greenhouse experiment 2012. Means with the same letter across nitrogen fertilizer rates, within each year are not significantly different at $p \leq 0.05$

Control water with deionized water
1:6 is a ratio of corn cob to water (10 kg of corn cob in 60 L of deionized water)
1:4 is a ratio of corn cob to water (15 kg of corn cob in 60 L of deionized water)

CHAPTER 3

CORN COB RESIDUE MANAGEMENT EFFECT ON SOIL HEALTH

ABSTRACT

The biofuel industry in the U.S. is using corn (*Zea mays* L.) residue as raw material for bioethanol production. However, there is a concern regarding the removal and management of corn residue effects on soil health. This concern has led to explore new alternatives for ethanol production, such as cellulosic ethanol production by utilizing corn cob as feedstock source. There are many management issues that need to be addressed in order to efficiently utilize corn cob residue for ethanol production. One of those parameters is the storage of the corn cob residue. Currently, storage methods include piling and baling loose corn cob residue at the edge of harvested fields for storage over winter. Unfavorable plant growth responses have been observed after storage of corn cob residue in the field. The objectives of this study were to investigate the effects of loose and baled corn cob residue storage methods on soil physical and chemical properties and to mitigate such effects on soil productivity.

The study investigated two storage methods at two different sites that were established in the fall of 2010, through the fall of 2012. The loose corn cob residue study was conducted at the Agronomy Research Farm at Iowa State University located near Ames, Iowa (AC site). The soil type is Canisteo silty clay loam (Fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls) and Harps loam (Loam, mixed, superactive, mesic Typic Calciaquolls). The treatments for the loose corn cob residue method consisted of two tillage systems of conventional tillage (CT) and no-tillage (NT), which represented the main treatment. Each tillage system was split into five corn cob residue treatments as Control, Removed Residue (7.5 cm applied in the fall and completely removed early spring), 2.5, 5.0, and 7.5 cm corn cob residue depths

randomly assigned at each tillage treatment and replication. Furthermore, each corn cob residue treatment was split to receive four N fertilizer rates of 0, 90, 180, and 270 kg N ha^{-1} randomly assigned at each corn cob residue treatment and replication. The N fertilizer was 32% liquid UAN (NH_4NO_3), which was side-dressed and injected in May after planting, using a spoke point injector (Baker et al., 1989). The AC site was planted on 6th May, 2011 and 14th May, 2012 using a 111 day maturity corn variety (Pioneer, P33W84) with a seeding density of 79,000 seeds ha^{-1}.

The second study was established at a Northwest Iowa farmer's field near Emmetsburg and near the POET, Biorefinery plant (ENW site). The soil type is Clarion loam (Fine-loamy, mixed, superactive, mesic Typic Hapludolls). The ENW site used a square corn cob residue bale as a storage method, with which bales were placed in the field after harvest and stored over winter but removed in the spring before planting. The main treatment consisted of corn cob residue left after bales removal: 1) Corn cob residue left on soil surface as results of breakdown of bales if any, 2) corn cob residue were completely cleaned or removed from each plot, and 3) control treatment, where no bales were placed on plots. Each of the corn cob residue treatments were split into four N fertilizer rates of 0, 90, 180, and 270 kg N ha^{-1} and randomly assigned at each corn cob residue treatments. The different N fertilizer rates were hand applied using granular urea in May after planting. The ENW site was planted on 5th May, 2011 and 25th April, 2012 using a 111 day maturity corn variety (Pioneer, P0448AM1), with a seeding density of 89,000 seeds ha^{-1}.

The agronomic parameters measured in the field study consisted of soil organic carbon (SOC), soil total nitrogen (STN), soil pH, microbial biomass carbon (MBC), organic acids, water stable aggregates (WSA), associated aggregate C content, bulk density (ρ_b), soil penetration resistance (SPR), and water infiltration (I_r). The findings from the study suggested that SOC, STN, soil pH, and organic acids were not affected by the different amounts of corn cob residue, N fertilizer rate, and the tillage system used in the field experiment. However, soil physical properties such as WSA, ρ_b, SPR, and I_r were affected by the amounts of corn cob residue left on the soil surface. The results showed a decrease in soil macro-aggregates across all corn cob residue treatments in 2011 as compared to 2012. At the same time SPR was affected by the amount of corn cob residue left on the soil surface and the degree of corn cob residue removal. Soil ρ_b was lower at 0-7.5 cm soil depth in general when compared with lower soil depths, and I_r was also affected by corn cob residue under the CT tillage system.

The findings suggest that removal of corn cob residue of loose pile or bale storage methods will moderate corn cob residue effects on soil physical and chemical properties (soil health). Also, removal of corn cob pile and bales should be particularly monitored, in order to minimize detrimental effects on soil health when large amount of corn cob residue are left in the storage area. A balanced management approach with adequate N fertilization along with tillage and removal of the loose and baled corn cob residue should reduce the effects of corn cob residue on soil health.

INTRODUCTION

The transformation of energy from the fossil fuel base to bioenergy sources encouraged the establishment of a new industry in the past two decades, which is dependent on corn (*Zea mays* L.) grain as the feedstock material for biofuel production. However, corn residue has been recently investigated by the bioenergy industry as a viable feedstock source for cellulosic ethanol production due to its abundance, encouraging bioenergy industry to establish ethanol plants (Dwivedi et al., 2009; Schubert, 2006). The use of corn grains and crop residue instead of fossil fuels has the potential to reduce greenhouse gas emission (Wilhelm et al., 2004; Graham et al., 2007). In addition to crop residue, an emerging source for ethanol production is corn cob. This source of feedstock along with its methods of collection and storage impose significant challenges to soil health (optimum function of biological, physical, and chemical properties).

Generally, corn cob residue is collected and piled or stacked as bales at the edge of the field after harvest for the duration of winter until the following spring. Field observations of corn planted where corn cob residue was stored over winter exhibited poor plant development and yield reduction the following season. In the Mid-west, where soils have inherently fine-texture with somewhat poorly-drained and excess soil moisture condition, storing and handling loose or baled corn cob residue in the field can have significant effects on soil environment. In such soil environment, proper crop residue management is necessary to provide an optimal seed zone condition for germination, seedling development, and plant growth (Swan et al., 1996).

Field storage of corn cob residue in pile or bales can have detrimental effects on soil health due to heavy field machinery and corn cob residue left after pile or bales removal. Such detrimental effects include soil compaction, surface runoff, soil erosion, and subsequent decrease in aboveground biomass and grain production (Wilhelm et al., 2004; Graham et al., 2007). In addition, careful consideration of crop residue management is essential in improving soil health characteristics to maintain high soil productivity and healthy crops (Karlen et al., 1994). Therefore, surface residue on poorly-drained soils, if not managed correctly may cause slow plant growth and development due to low soil temperature (Licht and Al-Kaisi, 2005; Kaspar et al., 1990; Bollero et al., 1996; Fortin and Pierce, 1991), which often leads to slow plant emergence and N mineralization (Al-Kaisi and Kwaw-Mensah, 2007).

Corn cob residue left on the soil surface after harvest can influence N availability early in the growing season; where colder soil temperatures will slow soil organic C (SOC) and N mineralization and subsequently plant N use or accumulation (Al-Kaisi and Licht, 2004; Licht and Al-Kaisi, 2005; Mehdi et al., 1999; Sainju and Singh, 2001). However, the collection and storage of corn cob residue may require change in the current tillage and N fertilization practices; in order to prevent potential soil compaction, soil erosion, soil organic matter loss, and soil nutrient depletion. Crop residue plays a critical role in protecting soil surfaces from wind and water erosion and thereby improving soil physical properties (Lindstrom, 1986), as well as increase SOC content, which has been shown to improve soil structure by enhancing aggregate stability, and decreasing bulk density (ρ_b), with higher water infiltration rates (Blanco-Canqui and Lal, 2007; Guzman and Al-Kaisi, 2011).

Therefore, corn cob residue management (storage and removal) may require the integration of management practices that include tillage and N application. As previously indicated the storage and removal of corn cob residue in poorly-drained soils; may lead to soil compaction and potential damage to soil structure. This may require the use of conventional tillage to temporarily correct its negative effects on soil temperature and water evaporation early in the spring (Mahboubi and La, 1998). Tillage system generally affect soil C losses by inducing SOC content oxidation shortly after tillage operations (Reicosky et al., 1997; Al-Kaisi and Yin, 2005), and the destruction of soil aggregates that physically protects SOC content from microbial activities (Six et al., 2000). However, adequate N fertilization can aid in soil C retention due to increase in aboveground biomass production as a source for SOC input (Wilts et al., 2004; Van Vleck and King, 2011). However, some studies have suggested that demands by the biotechnology industry may encourage farmers to switch to NT in order to offset the potential losses of SOC from crop residue removal (Kim and Dale, 2004).

The sustainability of corn cob residue removal and storage method will depend heavily on the cropping system (Doran et al., 1984), climate and soil type (Mu et al., 2008), for each region to minimize potential soil physical, chemical, and biological changes. We hypothesize that potential soil biological, physical, and chemical properties are affected by corn cob residue storage and removal. Creating soil condition that is not conducive for optimal plant growth and development. Therefore, the objectives of this study were to investigate potential effects of storage and processing of corn cob residue on soil health and suite of potential management practices, such as tillage system, N fertilizer rate, corn cob residue amounts, and their interaction effects on selected soil biological, physical, and chemical properties in Central and Northwest Iowa.

MATERIAL AND METHODS

Experimental sites and treatments

Loose corn cob experiment (AC site)

The study was established in the fall of 2010 on a Canisteo silty clay loam (Fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls) and Harps loam (Loam, mixed, superactive, mesic Typic Calciaquolls) soil association at the Iowa State University, Agronomy Research Farm (AC site) located in Central, Iowa (42.0^{o}'N; 93.8^{o}'W) . Before the study was established in the fall of 2010, the AC site was in a corn-soybean [*Glycine max* (L.) Merr.] rotation under conventional tillage (CT), which was chisel plowed in the fall and chisel plow plus disk in the spring. Source of N fertilizer used was liquid urea-ammonium nitrate 32% N (UAN), which was side-dressed injected in May after planting using agronomic rates of 170 kg N ha^{-1} (Blackmeter et al., 1997). Also phosphorus and potassium fertilization were applied as needed to maintain optimum fertility levels so as not to restrict corn or soybean growth.

The average annual temperature and annual precipitation at the AC site for 2011 was 8.7 ^{o}C and 807 mm, respectively. During 2012, the average annual temperature was 11.4 ^{o}C and annual precipitation was 512 mm (Fig. 3.1). Treatments were established to monitor the changes in plant growth and development under loose corn cob residue in a randomized complete block design with split-split arrangement with three replications in a continuous corn cropping system for the duration of the study. The dimension of each plot was 6.1 m wide by 7.6 m long with three meter borders between plots and replications.

The AC site consisted of two randomized tillage systems conventional tillage (CT) and no-tillage (NT), which represents the main treatment. Tillage system CT was conducted in the spring within a week after corn cobs residue removal treatment was performed, using a commercially available model with straight shanks and twisted sweeps. The shanks were mounted on four tool bars in a staggering order to ensure an effective spacing of 30 cm between shanks. The depth of tillage with chisel plow was 22-25 cm. A field cultivator was then used for secondary tillage, using a horizontal implemented frame section with straight shanks and smoothing arrow at the end. The NT system has no disturbance besides application and removal of corn cob residue (removed treatment only), seed planting, and N fertilizer application.

Each tillage system was split into five corn cob residue treatments as Control, Removed Residue (7.5 cm applied in the fall and completely removed early spring), 2.5, 5.0, and 7.5 cm corn cob residue depths randomly assigned at each tillage treatment and replication. The desired corn cob residue treatments were based on our first field evaluation at four different sites in Emmetsburg, Iowa in 2009-2010, where corn cob residue were piled in-field areas of 9.1 m width by 30.5 m long. After, corn cob piles were removed by farmers; noticeable amount of residue ranging from 2.5 to 7.5 cm depth of corn cob residue was left on the soil surface

(Fig.3.2). In the fall of 2010, corn cob residue treatments were established for the 2011 rowing season based on the above observations using loose corn cob residue (70% corn con and 30% corn stalks and leaves) provided by POET Biorefinery from Emmetsburg, Iowa. The corn cob residue for each treatment depth was based on spreading corn cob residue on an experimental plot, which was weighted on a field scale to determine equivalent amount to each designed depth. The corn cob residue equivalent to each treatment depth was then hauled and spread using hand-hoes to each respective plot using a field cart. For the 2012 season, the same corn cob residue treatments were kept on the same plots, except for the removed residue treatment, where fresh corn cob residue was applied again in the fall of 2011 after corn harvest and removed early spring 2012.

Furthermore, each corn cob residue treatment was split to receive four N fertilizer rates of 0, 90, 180, and 270 kg N ha^{-1} randomly assigned at each corn cob residue treatment and replications. The N fertilizer source was 32% liquid UAN (NH_4NO_3), which was side-dressed and injected in May after planting, using a spoke point injector (Baker et al., 1989). The AC site was planted on 6th May, 2011 and14th May, 2012 using a 111 day maturity corn variety (Pioneer, P33W84) with a seeding density of 79,000 seeds ha^{-1}.

Corn cob bales experiment (ENW site)

The study was established in the fall of 2010 on a Clarion loam (Fine-loamy, mixed, superactive, mesic Typic Hapludolls) soil association on a field near Emmetsburg in northwest Iowa (ENW) (43.1^{o}'N; 94.7^{o}'W). Before the study was established in the fall of 2010, the ENW site was in corn-soybeans [*Glycine max* (L.) Merr.] rotation under conventional tillage (CT), which was chisel plowed in the fall and chisel plus disk in the spring. Source of N used was liquid urea-ammonium nitrate 32% N (UAN), which was side-dressed injected in May after planting using agronomic rate of 170 kg N ha^{-1} (Blackmeter et al., 1997). Also, phosphorus and potassium were applied as needed to maintain fertility level so as not to restrict corn or soybean growth.

The average annual temperature and annual precipitation for 2011 was 7.4 ^{o}C and 709 mm, respectively. In 2012, the average annual temperature was to 9.8 ^{o}C and annual precipitation was 559 mm (Fig. 3.18). Treatments were established to monitor changes in plant growth and development under corn cob bales residue (70% corn stalks and leaves and 30% corn cob) in a randomized complete block design with split-split arrangement with CT system, and three replications in a continuous corn cropping system for the duration of the study. The dimension of each plot size was 6.1 m wide by 7.3 m long with three meters borders between plots and 12.2 m wide buffer zone between corn cob bales treatments. The buffer zones between corn cob bales were established to prevent excessive snow accumulation during winter to ensure uniform moisture distribution in areas between corn cob bales.

The ENW site consisted of three randomized corn cob residue treatments after bales removal, which represents the main treatment. Corn cob bales placement occurred in the fall of 2010 and 2011 after harvest, then corn cob bales were removed the following spring of each year. Corn cob bale management at the ENW site consisted of the following treatments after bales removal: 1) corn cob residue left on the soil surface as results of bales breakdown during the removal process if any, 2) corn cob and other residue were completely cleaned from each plot after bale removal, and 3) control treatment where no bales were placed on plots (Fig. 3.19). Corn cob bales and residue treatments were used on the same plots every year. Furthermore, each of the corn cob residue treatments was split into four N fertilizer rates of 0, 90, 180, and 270 kg N ha^{-1}. The different N fertilizer rates were weighed using portable scale (ULINE H-1651 shipping supply specialist, Pleasant Prairie, WI) within a range of + /– 0.05 kg granular urea. Then each N fertilizer rate was hand applied in May after planting at each related plot. The ENW site was planted on 5th May, 2011 and 25th April, 2012 using a 111 day maturity corn variety (Pioneer, P0448AM1), with a seeding density of 89,000 seeds ha^{-1}.

Soil organic carbon, total nitrogen, bulk density, and soil pH measurements

Soil samples were collected from each site in mid-October after harvest prior to the establishment of treatments in 2010. Those soil samples were analyzed to establish the baseline for the different parameters of the soils prior to the start of both studies. Furthermore, soil samples were taken for soil organic carbon (SOC), soil total nitrogen (STN), soil bulk density, and soil pH at both sites during the study including: fall 2011 and fall 2012. Soil sampling was done by collecting twelve 1.7 cm diameter soil cores from different depths; 0-7.5, 7.5-15, and 15-30 cm for each treatment plot. A total of 10-12 soil cores were collected from each depth and were mixed and passed through a 2 mm sieve. The sieved soil samples were air dried before being analyzed for SOC and STN concentrations by dry combustion using CN analyzer (TRUSPEC, LECO Corporation, St. Joseph, MI). Also, soil samples were processed to measure soil pH (1:1 soil to water ratio) using an AR15 pH meter (Accumet® Research, Fisher Scientific International Inc.). Soil samples with pH values greater than 7.1, a separate inorganic C analysis was done to measure the inorganic C concentration for correction of the total soil C values obtained by dry combustion analysis, by subtracting it from the total soil C results to obtain soil organic C. The inorganic C determination was done by using a modified pressure calcimeter method (Sherrod et al., 2002).

Soil sampling for soil bulk density (ρ_b) was simultaneously done during the soil sampling for total C and N for each depth by taking three 1.7 cm diameter soil cores from each treatment plot for 0-7.5, 7.5-15, and 15-30 cm soil depths. Soil cores were carefully removed from probes and placed in paper bags. Once in the lab, the soil samples were oven dried at 105 °C for 24 hours and weighed. The dried soil mass was divided by the soil core volume to determine ρ_b in Mg m^{-3} in order to convert SOC and STN concentrations (mg g^{-1} dry soil) to mass for each depth per area for the baseline and 2011-2012 SOC and total N data. The SOC and STN concentrations values were multiplied by the mean ρ_b value and soil depth to obtain the SOC and STN contents in Mg ha^{-1}.

Soil microbial biomass carbon

Soil samples for the determination of microbial biomass carbon (MBC) were collected from the AC site at four different times during the growing season in both years. Soil samples were collected after planting in mid-May and subsequent samples were taken in mid-June, mid-July, and mid-September at specific experimental plots, which include control, removed, 2.5 cm and 7.5 cm corn cob residue treatments with 0, 180, and 270 kg N ha^{-1} rate only due to time and workload constraints. At ENW site, MBC soil samples were collected after planting in mid-May and after harvest in mid-September in both years at each experimental plot.

The MBC was determined by performing a fumigation extraction (Horwath and Paul, 1994), where six 1.7 cm diameter soil cores were taken at each treatment plot for the top 15 cm depth. The soil samples were then taken back to the lab and immediately sieved through 4 mm sieves at field moisture condition. At that point 20 g of soil sample was weighed for each treatment to be used for the non-fumigated sample, while another 20 g of soil sample was weighed and placed in a vacuum desiccator to be fumigated with ethanol-free chloroform ($CHCl_3$) for 24 hours. After the fumigation process, both soil samples from the same treatment plot were mixed with 100 mL of 0.5 M potassium sulfate (K_2SO_4) and placed in a shaker for 30 minutes, after which each sample was filtered through a Whatman No. 42 filter paper. In order to determine the background level of C in the filter paper and extract, a blank sample made of 0.5 M potassium sulfate (K_2SO_4) was filtered through filter paper. The filtered solution C was measured with an Elementarliqui-TOC carbon analyzer (Americas Inc., Mt. Laurel, New Jersey). The MBC for the soil was calculated on oven dry weight basis.

Soil organic acids

Organic acids present in the soil were determined by using capillary electrophoresis (CE) system (Beckman Coulter P/ACE MDQ, Fullerton, CA). The CE has become very popular due to its accurate and precise measurements and more standardized analytical tool for organic acids measurements. The mobility of organic acids needs to be matched and followed as close as possible to track their concentrations in the soil. Thus, several organic acids standards were run using the CE before soil measurement started. Some of the organic acids standards used were: butyric acid, citric acid, formic acid, malic acid, oxalic acid, succinic acid, and tartaric acid. These organic acids were selected based on potential existence in crop residue (Dilara and Parker 2007). The CE procedure used to measure extracts was done as outlined by Li et al. (2003).

Soil samples used for soil organic acid extractions were collected after planting in mid-May (spring) and after harvest in mid-September (fall) for the AC site. Six 1.7 cm diameter soil cores for the top 15 cm soil depth were taken at specific experimental plots; which include control, removed, and 7.5 cm corn cob residue treatments with 180 kg N ha^{-1} N rate only due to time and workload constraints. Soil cores were transported to the laboratory and passed through a 4 mm sieve. Then 10 g of soil was taken from each sample and shaken with 20 mL deionized water for 4 hours. The extracts were then vacuum-filtered through Whatman No. 42 filter papers until all liquids were separated from the extracts. Final sample products were then immediately frozen and sent to the protein facility laboratory at Iowa State University, where each sample was filtered again through a Millipore 0.45 µm membrane filter before being injected into the CE system. Values given by the CE system were expressed in mM, which was later converted to mg kg^{-1} of soil using molecular weights and a dilution factor.

Water stable aggregates, mean weight diameter, and soil aggregate fraction associated carbon

Soil samples for water stable aggregates (WSA) measurements were taken at both sites in mid-October after harvest prior to the establishment of treatments in fall 2010. In order to measure any changes in soil aggregates stability, both sites were sampled two times during the study including: fall 2011 and fall 2012. Soil samples collected from both sites in fall 2010 were analyzed to establish the baseline data of the soil physical properties prior to the start of both experiments. At the AC site a single soil core was randomly taken using a 7.6 cm diameter golf course hole- cutter to a soil depth of 15 cm from control, removed, 2.5, and 7.5 cm corn residue treatments with 0, 180, and 270 kg N ha^{-1} N rates due to time and workload constraints. At the ENW site all experimental plots were sampled. Then soil samples were carefully transported to the laboratory where they were gently passed through an 8 mm sieve. Through this process, undesirable materials such as plant residue, rocks, corn cob, and grains were removed from the sample. The soil samples were then air-dried and ready for analysis following the procedure by Kemper and Rosenau (1986).

With the soil samples ready to be analyzed, 100 g of soil was weighed from each sample and placed at the top of a set of six sieves staked top to bottom as follow: 4, 2, 1, 0.50, 0.25, and 0.053 mm, respectively. The set of six sieves was then submerged into a wet aggregate apparatus container filled with deionized water at 21 ºC and vertically oscillated for 5 minutes with a stroke length of 2 cm. The frequency of oscillation was maintained at 90 strokes min^{-1}. The wet aggregate apparatus is a custom made machine in which the 20-cm diameter sieves could be fitted (Guzman and Al-Kaisi 2011). It was noted, that the soil passed through the last sieve after 5 minutes of constant stroking was considered as aggregate size of <0.053 mm. Soil sample from each aggregate size sieve was washed into tubs using deionized water and oven dried at 65^{o}C until all water in the tubs had evaporated, then weight of each aggregate size fraction was determined. The WSA for each fraction size was expressed as a percentage of the total sample weight and as mean weight diameter (MWD) using the following equation (Youker and Mcguiness, 1957):

$$MWD = \sum_{i=1}^{7} \bar{x}_i \; w_i \qquad [1]$$

Where, i is one size fraction, $\bar{x}_i$ is the mean diameter of a size fraction, and w_i is the weight fraction of aggregates of the total sample. The different soil aggregates sizes were kept in coin envelopes (5.7 cm x 8.9 cm) and later analyzed for SOC concentration by dry combustion using CN analyzer (LECO Corporation, St. Joseph, MI).

Soil penetration resistance

Soil penetration resistance (SPR) readings were taken at both sites following the application of treatments. In order to follow changes in soil penetration resistance after the treatments were applied, sites were sampled two times during the study including: spring 2011, and spring 2012. The SPR was determined using a Rimik CP-20 penetrometer (Soil Measurement System, Tucson, AZ). The penetrometer used a 30° cone with a 1.27 cm diameter base. The penetrometer used a targeted insertion speed between 1.3 m min^{-1}, with a range of 0.01 to 2 m min^{-1}. The SPR measurements were conducted for tillage and corn cob residue treatments, N fertilizer rates were not taken into account due to time and workload constraints, where three insertion points per corn cob residue treatment were recorded at 2.5 cm soil depth increments down to 60 cm. Insertion points were randomly taken at each treatment plot.

Water infiltration

Water infiltration rate was measured at the AC site in mid-July in 2012 at specific experimental plots, which include control, removed, 2.5cm and 7.5cm corn cob residue treatments with 0,180, and 270 kg N ha^{-1} rate only due to time and workload constraints. Water infiltration rate was conducted using the Cornell Sprinkle Infiltrometer (Cornell University, Ithaca, New Yoek) (Ogden et al., 1997). The infiltrometer is a portable rainfall simulator that is carried to the field and placed on top of a single 24.1 cm inner diameter metal ring, which was pound into the soil to the depth of 7 cm between corn rows. The metal ring has an outlet where an overflow plastic tube was attached to collect and measure the volume of run off in a 500 ml plastic beaker, the time for the runoff and the runoff rate. In order to measure water infiltration, a constant rainfall intensity rate of 0.45 cm min^{-1} is kept. Runoff was collected at intervals of three minutes until steady runoff volume was obtained. Water infiltration rate (I_r) was calculated by using the following equation:

$$I_r = r - r_{ot} \qquad [2]$$

Where, r represents rainfall intensity in cm min^{-1}, and r_{ot} is the surface runoff rate in cm min^{-1}.

Due to the use of a single metal ring, a three-dimensional flow correction was employed. A model called Field Saturated Infiltrability, which takes into account soil type and ring insertion depth effects on I_r was used to correct the measurements (Reynolds and Elrick., 1990). This model uses empirical factors with the metal ring inserted to the depth of 15 cm in a silty clay loam soil. Therefore, for our study, a factor of 0.80 was used to take into account the horizontal flow at the bottom of the ring.

Statistical analysis

Data was analyzed using the statistical analysis procedure of PROC MIXED (SAS Institute, 2002). For the AC site, tillage system was considered as the main plot treatment, which was split into different corn cob residue levels, which was further split into N fertilization rates as split- split-plot by year. At the ENW site, main plot treatments were the corn cob residue treatments and each main plot treatment was split into different N fertilization rates as split-plot by year. Mean separation was determined using the PDIFF procedure, and significance difference was determined at $p \leq 0.05$, unless otherwise stated.

RESULTS AND DISCCUSION

Loose corn cob experiment (AC site)

Soil organic carbon, soil total nitrogen, and soil pH

Soil organic carbon (SOC) and soil total nitrogen (STN) contents were primarily affected by loose corn cob residue and N fertilizer rates at different soil depths. However no changes were observed with different tillage systems. Thus, an average across tillage systems ($p=0.0942$ for SOC and $p=0.8962$ for STN) was used in Fig. 3.3, 3.4, 3.5, and 3.6. Changes in SOC and STN contents within each soil depth across corn cob residue treatments showed no differences (Fig. 3.3 and Fig. 3.5). However, changes in SOC content at 7.5-15 cm soil depth showed a decline for the 2.5 and 7.5 cm corn cob residue depth treatments as compared to the 0-7.5 cm soil depth across all corn cob residue treatments. At the 15-30 cm soil depth, a decline in SOC was observed across all corn cob residue treatments compared to 0-7.5 cm and 7.5-15 cm soil depths with the exception of 2.5 cm corn cob residue at 7.5 cm soil depth (Fig. 3.3). Furthermore STN content at lower soil depths (7.5-15 and 15-30 cm) across corn cob residue treatments showed significantly lower STN content, with the exception of 2.5 cm corn cob residue at 7.5-15 cm soil depth when compared to the top 7.5 cm soil depth (Fig. 3.5). Generally, SOC and STN contents decline was observed at 7.5-15 and 15-30 cm soil depths regardless of corn cob residue treatments and N fertilizer rates (Fig. 3.4 and 3.6). There were no changes in SOC and STN contents due to corn cob residue and N fertilizer rates within each soil depth. In general, a decrease in SOC and STN contents was observed as soil depth increased across all corn cob residue treatments and N fertilizer rates (Fig. 3.4 and 3.6).

The lack of differences in SOC and STN contents between CT and NT systems in this experiment is perhaps due to the time of implementation of NT and residue treatments (Ellert et al., 2001). Nevertheless, a positive change in SOC and STN contents was observed at the top 7.5 cm soil depth, which might be due to the large amount of loose corn cob on the soil surface, which resulted in the increase of organic matter input and a possible decrease in SOC mineralization rate (Paustian et al., 2000; Follett, 2001). Conversely, the negative changes in SOC and STN contents at the 15-30 cm soil depth across all corn cob residue treatments can be explained by the difficulty of crop residue incorporation in the soil at that depth for NT and CT (tillage depth between 22-25 cm) (Staricka et al., 1991).

Soil pH was not significantly different between years (p=0.9749), thus an average for both years was used in Fig. 3.7 and Fig. 3.8. An interaction effects between tillage system and N fertilizer rate (Fig. 3.7); and corn cob residue, N fertilizer rate, and soil depth (Fig. 3.8) on soil pH were observed. Generally, CT showed lower soil pH values with 270 kg N ha^{-1} compared to 0 and 180 kg N ha^{-1}. There were no differences across all N fertilizer rates for NT. Nevertheless at 180 kg N ha^{-1}, CT showed higher soil pH values compared with NT at 180 kg N ha^{-1} and CT and NT at 270 kg N ha^{-1} (Fig. 3.7). An interaction between soil depth, corn cob residue, and N fertilizer rates is shown (Fig. 3.8). Generally, corn cob residue treatment and N fertilizer rate within each soil depth showed no change in soil pH across all corn cob residue and N fertilizer treatments. However, some variation in soil pH values was observed, which could be explained by the spatial variability within the plots, soil type, and the uniformity of N fertilizer application (Hangsheng et al., 2005).

Soil microbial biomass carbon and organic acids

Microbial biomass carbon (MBC) refers to the amount of soluble carbon within the microbial community and a biological indicator for soil health, and can be a sensitive indicator to environmental changes (Sparling, 1992). Highly productive soils have been related to high levels of MBC between 216-375 µg C g^{-1} dry soil (Alves de Castro Lopes et al., 2013). At the AC site soil MBC samples were taken during summer, in order to measure effects of the applied treatments. Results of soil MBC are presented as an average across tillage and N fertilizer rates ($p=0.1983$ and $p=0.7177$ for 2011 and 2012, respectively), due to the lack of significance effects on soil MBC (Fig. 3.9). Soil MBC throughout the summer for the 2.5 cm and 7.5 cm corn cob residue depth treatments was greater than those for the control and removed residue treatments. This trend was especially observed in mid-summer (June and July), where differences were greater at 2.5 cm and 7.5 cm residue depths than the control and removed corn cob residue treatments. It is expected to observe peaks of MBC during mid-summer (Kaiser and Heinemeyer, 1993 and Bardgett et al., 1999), which is related to organic matter input (He et al., 1997), and the decomposition of these organic materials throughout the season. The corn cob residue 2.5 cm and 7.5 cm treatments in the short time of this study showed more influence than tillage system and N fertilizer rate, which are in agreement with Spedding et al. (2004).

Soil organic acids are usually not present in large quantities in the soil as most organic compounds exuded from roots or crop residue decomposition. In soil organic acids undergo degradation and sorption after they are released into the soil, where this degradation might reduce soil organic acids concentration (Jones et al., 1996). However, their presence in the soil exerts a very strong influence on soil micro-organisms and may affect plant nutrients availability (Rovira et al., 1969). Soil organic acid samples for the AC site experiment were taken in the spring and fall. Oxalic and butyric acids were the only organic acids that were detected during the first year of the field experiment at the AC site and the results of soil organic acids sampling period and corn cob residue treatment for 2011 are presented in Fig. 3.10. In the 2012, growing season, no soil organic acids were detected due to severe drought and high temperatures during the growing season. Therefore, no concentrations for oxalic or butyric acids are presented. In 2011, oxalic acid concentrations were greater in the spring for the control and removed residue treatments than that during the spring for 7.5 cm corn cob residue treatment. In the fall of 2011, oxalic acid concentration decreased across all corn cob residue treatments. The other detected soil organic acid, was butyric acid, where its concentration was not different across all corn cob residue treatments within each season, but higher concentration was observed in the fall than in the spring across all corn cob residue treatments.

These low molecular weight organic acids (oxalic and butyric) found in soil with the residue treatments can be attributed to plant roots, micro-organisms, and the degradation of soil organic matter (Sposito et al., 1982). Oxalic and butyric organic acids are exuded by root plants and commonly found in the rhizosphere (Ahumada et al., 2001 and Marschner and Dell. 1994). The degradation of these organic acids is quick in a typical soil environment. However, they can also be produced throughout the life cycles of soil microbes and plants and they typically occur in the rhizosphere or under plant litter (Krishnamurti et al., 1997). In 2012, no concentrations were detected across all corn cob residue treatments. This observation can be explained by the fact that in 2012, much of the free organic acids exuded from the roots were possibly degraded rapidly by soil microbial biomass, or were sorbed to the soil anion exchange sites (Jones et al., 1996).

Water stable aggregates and soil aggregates associated carbon

Water stable aggregates (WSA) were measured at the AC site to determine changes in soil structure at the aggregate level. There was interaction effect between years, corn cob residue treatments, and aggregate size. However, tillage system and N fertilizer rate showed no effects on aggregate stability in both years ($p=0.8698$ and $p=0.8447$ for 2011 and 2012, respectively). Therefore, an average of the same aggregate fractions across tillage and N fertilizer rate were used in Fig. 3.11. In both years at the AC site, corn cob residue treatments showed no effect on WSA percentage within each aggregate size fraction. The distribution of aggregates was separated into seven aggregate size fraction (<0.053, 0.053-0.25, 0.25-0.50, 0.50-1, 1- 2, 2- 4 and >4 mm). For the purpose of this discussion the following size fractions of 0.50 to >4 mm was named as macro-aggregates and the size fractions of 0.053 to 0.50 mm as micro-aggregates. An average across tillage systems, N fertilizer rates, and corn cob residue treatments for macro-aggregates accounted for the 58%, while micro-aggregates accounted for 42% of the total dry soil weight of all aggregates for 2011. However, in 2012 macro-aggregates decreased by 8%, while micro-aggregates increase by 2%. Furthermore, aggregate size fraction of 2-4 and 1-2 mm were the most affected at the macro-aggregates range with a decrease of 6.3% and 3.1% across all corn cob residue, respectively, from 2011 to 2012 (Fig. 3.11). With the decrease in WSA percentages for macro-aggregates, an increase in micro-aggregates in 2012 was observed. Micro-aggregates size fractions of 0.25-0.5 and 0.053-0.25 mm increase by 0.54 % and 1.07%, respectively, across all corn cob residue treatments from 2011 to 2012 (Fig. 3.11). The decrease in macro-aggregates after two years of residue and tillage treatments can be attributed to changes in soil environment (Soulides and Allison, 1961; Tisdall et al., 1978; Lehrsch et al., 1991; and Mulla et al., 1992) and machinery traffic during tillage operations, corn cob residue treatments, and N fertilizer application.

Mean weight diameter (MWD) of aggregates, which is the calculation across all aggregates sizes to convert it into a single value, in order to make comparison across management practices was used to represent the interaction between year and all management practices (Fig. 3.12). In general, tillage system showed effects on MWD, where NT had greater MWD than CT in 2011 and 2012 by 0.11 mm and 0.24 mm, respectively. However, corn cob residue treatments within each N fertilizer rate showed no effect in 2011 and 2012. The favorable effect of NT on MWD compared to CT can be attributed to the soil surface protection by crop residue and the enhanced activity of earthworms (Lal et al., 1994).

The associated aggregates C content was primarily affected by aggregate size fraction and corn cob residue treatments in 2011 and 2012. No differences were observed due to tillage system and N fertilization ($p=0.0932$), thus an average across corn cob treatments was used in Fig. 3.13. Corn cob residue treatments at the AC site showed no effect on aggregate associated C in both years. An average across all corn cob residue treatments for the macro-aggregates associated C content in 2011 was 5.91 g C kg^{-1}, whereas micro-aggregates associated C content was 4.97 g C kg^{-1}. In 2012, a decrease in macro-aggregates associated C content was 0.77 g C kg^{-1}, while an increase in micro-aggregates associated C content was 0.16 g C kg^{-1}. The macro-aggregates fractions of 2-4 and 1-2 mm sizes across all corn cob residue treatments show a decline in aggregates associated C content of 2.58 g C kg^{-1} and 1.31 g C kg^{-1}, respectively, from 2011 to 2012. Also, an increase in micro-aggregates C was observed for the 0.25-0.50 and 0.053-

0.25 mm size fractions of 0.10 g C kg^{-1} and 0.22 g C kg^{-1}, respectively, from 2011 to 2012 (Fig. 3.13). The correlation between WSA percentage and its aggregate associated C content can be explained by the aggregate hierarchy theory of soil aggregate fractions arrangement, for aggregation decrease or increase and loss or gain of soil organic matter (Elliot, 1986; Cambardella and Elliot, 1993). In this arrangement micro-aggregates are protected by macro-aggregates and significant amount of fresh C will be protected as well from microbial activities. Also it is expected that cultivation can reduce soil WSA percentage and its associated C content due to the disturbance and change in its aggregate distribution (Six et al., 1999). Nevertheless, no differences were found between tillage systems. This can be attributed to the short period of time since the implementation of tillage treatments and the application of loose corn con in this study.

Soil bulk density and soil penetration resistance

Soil bulk density (ρ_b) was measured for the AC site to understand the effect of different amounts of corn cob residue on the soil physical properties. Interaction between year, soil depth, and corn cob residue treatments was observed. However, no differences in bulk density due to tillage system and N fertilizer rate were found (p=0.3108 and p=0.1425 for 2011 and 2012, respectively), thus an average was used in Fig. 3.14. In general, treatments with 7.5 cm corn cob residue depth showed a lower ρ_b than that with the control, removed residue, and 2.5 cm corn cob residue treatments, across all soil depths and years. Over two years, there was a reduction of approximately 6.32 % in ρ_b with the 7.5 cm corn cob residue treatment. This can be explained by the large amount of residue left on the soil surface promoting better soil condition. Crop residue encourages earthworm activity and protects soil from water erosion, which contributes to a decrease in ρ_b (Lal et al., 1994). Tillage system showed no effects on ρ_b, which means that the incorporation or not of loose corn cob residue into the soil has little effect on ρ_b in during the short time of this study.

Soil penetration resistance (SPR) is another indicator for measuring treatments effect on soil physical properties. The SPR was measured during spring 2011 and 2012 before planting, in order to understand and determine management effects. Tillage system and corn cob residue treatments interaction on SRP are presented in Fig. 3.15. In general, SPR values under CT and NT in both years show that control treatment and removed residue had a greater SPR compared to 2.5 cm and 7.5 cm corn cob residue treatments at the top 15 cm. On average, control and removed residue treatments SPR across tillage system and soil depths were greater than that at 2.5 cm and 7.5 cm corn cob residue treatments for 2011 and 2012 by 0.25 MPa and 0.02 MPa, respectively. Differences in SRP values between corn cob residue treatments were not significant at lower soil depths for both tillage systems in both years. The increase in SPR values at the 15 cm soil depth for the control and removed treatments can be attributed to field operation, traffic, and removal of crop residue; while treatments of 2.5 cm and 7.5 cm corn cob residue treatments had less exposure to traffic (corn cob residue covering soil surface), except during application of corn cob treatments during 2011. The lower SPR values observed in 2012 across all corn cob residue treatments and tillage system can be due to dry soil conditions and the presence of corn cob residue on the soil surface to minimize soil compaction (Medvedev and Cybulko 1995).

Water infiltration rate

Water infiltration rate (I_r) measured at the AC site in mid-summer of 2012 showed an interaction between tillage systems, corn cob residue, and N fertilizer rates (Fig. 3.16). In general, water infiltration rate in the CT plots with 2.5 cm and 7.5 cm corn cob residue treatments was greater than that for the control and removed corn cob residue treatments across all N fertilizer rates. Previously mentioned MWD aggregates for 2012 across corn cob residue were not different; however, it was observed that 2.5 cm and 7.5 cm corn cob treatments had slightly higher MWD aggregates than the control and removed corn cob residue treatments for CT, but no differences were observed for NT across corn cob residue treatments (Fig. 3.12). Also, the 2.5 cm and 7.5 cm treatments showed slightly lower ρ_b values than the control and removed treatments for 2012 (Fig. 3.14). These changes in MWD and ρ_b may contribute to the high I_r in 2012 for 2.5 and 7.5 cm corn cob residue treatments across N fertilizer rates. In general, under NT system across all corn cob residue treatments, I_r rates showed no differences for different N fertilizer rate treatments, with the exception of 0 kg N ha^{-1}, where the control and removed residue treatments had greater I_r rate than that for 2.5 cm and 7.5 cm corn cob residue treatments. The lack of differences in I_r rate in NT system across all corn cob residue treatments may be due no changes in MWD and ρ_b for NT.

The steady state of I_r rate where soil moisture at field capacity with 2.5 cm and 7.5 cm corn cob residue treatments were higher compared to that with the control and removed corn cob residue treatments for CT, but it was not observed in NT (Fig. 3.17). The high value of a steady state of I_r rate may be due to the high amount of corn cob residue covering the soil surface, which decreased the ρ_b and increase MWD in aggregates (Fig. 3.12 and Fig. 3.14, respectively). Also, the lower steady state of I_r rate observed with the control and removed can be explained by the lack of crop residue cover and the removal operations, which potentially caused soil surface compaction and sealing of the bare soil surface as demonstrated by higher ρ_b (Lindstrom, 1986; Blanco-Canqui and Lal, 2007).

Corn cob bales experiment (ENW site)

Soil organic carbon, soil total nitrogen, and soil pH

An interaction between corn cob residue left after bale removal treatments and soil depths was observed for SOC and STN contents from 2011 to 2012. However, N fertilizer treatments showed no differences in SOC and STN contents ($p=0.5540$ for SOC and $p=0.9349$ for STN, respectively). Thus an average for SOC and STN contents across N fertilizer rates for different corn cob residue treatments after bale removal and soil depths are presented in Fig. 3.20 and 3.21. The top soil depth of 0-7.5 cm and 15-30 cm show a decline in SOC content across all corn cob residue treatments compared to the 7.5-15 cm soil depth (Fig. 3.20). However, STN content showed a greater decline at the top 0-7.5 cm compared to that at the 7.5-15 cm and 15-30 cm soil depths across all corn cob treatments (Fig. 3.21). The decline in SOC and STN contents can be attributed to tillage effect and potential soil erosion at this site (Gregorich et al., 1998). The ENW experiment site has slight slop of 1-2%, where the experiment was conducted. Also this area was greatly affected by machinery traffic during bales removal, which contributed to soil compaction and erosion.

At the ENW site, the soil pH ranged between 5.9 and 5.6 for 2011 and 2012, respectively. These values indicate a slightly acidic soil condition. Different N fertilizer rates showed no differences for soil pH ($p=0.1432$ and $p=0.2386$ for 2011 and 2012, respectively), thus an average across all N fertilizer rates was used in Fig. 3.22. In general, at the top 0-7.5 cm soil depth, no differences in soil pH were observed between corn cob residue treatments in both years. However, at the 7.5-15 cm and 15-30 cm soil depths, soil pH in 2011 was higher than that in 2012 across all corn cob residue treatments. No significant trend in soil pH was observed across corn cob residue treatments, which showed that variability in soil pH values could be due to soil spatial variability, soil texture differences, and non-uniformity of N fertilizer application (Hangsheng et al., 2005).

Soil microbial biomass carbon

Microbial biomass carbon (MBC) is the amount of soluble carbon within the microbial community and a biological indicator for soil health, which is also a sensitive indicator for environmental changes (Sparling, 1992). Highly productive soils have been related to high levels of MBC between 216-375 µg C g^{-1} dry soil (Alves de Castro Lopes et al., 2013). Soil samples for MBC were taken at two different times at the ENW site. The first soil sampling was after the removal of corn cob bales and the second was taken after harvest. In general, there was no difference in soil MBC across all N fertilizer rates ($p=0.6254$ and $p=0.9760$ for 2011 and 2012, respectively), therefore an average was used in Fig. 3.23. Generally, it was found that soil MBC in the fall (after harvest) in both years across all corn cob residue treatments showed greater MBC than that in the spring (after bale removal). However, no differences in soil MBC were observed across corn cob residue treatments within each season (spring or fall) for both years. In fall 2011, MBC was greater across all corn cob residue treatments than in the spring of 2011. However, in 2012, MBC in the fall across all corn cob residue treatments shows slight increase over that in the spring of the same year. No differences in MBC were observed between residue treatments with the exception of left corn cob residue treatment in 2012. The fall MBC values in both years and across all corn cob residue treatments show no differences. However, in the spring, the MBC across all corn cob residue treatments in 2011 was lower compared to that of spring 2012 with the exception of left corn cob residue treatment. Even though, differences in MBC were observed between sampling periods, the lack of interaction with corn cob residue show that corn cob bale storage and removal did not affect soil MBC during the short time of this study. The greater values of MBC in both years across all corn cob residue treatments during fall can be explained by the increase in organic matter at the soil surface after harvest (He et al., 1997), and the decomposition of these organic materials throughout the season.

Water stable aggregates and soil aggregates associated carbon

The storage of corn cob residue bales over winter might have a detrimental effect on soil structure at the aggregate level. There was an interaction effect between years, corn cob residue treatments, and aggregate size on WSA percentage. The N fertilizer rate showed no effect on WSA percentage (p=0.8947 and p=0.9961f or 2011 and 2012, respectively). Thus an average across all N fertilizer rates was used (Fig. 3.24). Generally, WSA distribution was separated into seven aggregate size fractions (<0.053, 0.053-0.25, 25-0.50, 0.50-1, 1-2, 2-4, and >4 mm). For the purpose of this discussion the following size fractions of 0.50 to >4 mm was named as macro-aggregates and the size fractions of 0.053 to 0.50 mm as micro-aggregates.   An average cross N fertilizer rates and corn cob residue treatments accounted for the 56% macro-aggregates and 48% micro-aggregates of the total dry soil aggregates weight for 2011. In 2012, macro-aggregates show a decrease of 15%, while micro-aggregates increased by 4% across all corn cob residue treatments. The WSA percent of each size fraction showed no differences across corn cob residue treatments in both years. In 2012, a decrease in WSA percentages is observed at 0.50-1.0, 1-2, 2-4, and >4 mm size fractions by and 2.8%, 4.2%, 4.3%, and 3.7%, respectively. Also, an increase in WSA percentages is observed at 0.053-0.25 and <0.053 mm size fraction by 4.3% and 4.6%, respectively. The ENW site was under a CT system and it was observed that at the 15 cm soil depth macro-aggregates percentages were reduced in 2012. The decrease in macro-aggregates with CT can be due to the disruption of soil structure by tillage operations and equipment traffic during bales removal, which caused soil structure deterioration (Horn et al., 1995; Six et al., 2000).

Mean weight diameter (MWD) of soil aggregates, which is the calculation across all aggregates size fractions to convert it into a single value was used to evaluate the interaction effects of management practices on WSA percentages. There were no differences in MWD due to N fertilizer rates (p=0.4043 and p=0.8322 for 2011 and 2012, respectively), thus an average was used (Fig. 3.25). In general, in 2011 across all corn cob residue treatments, no differences in MWD values were observed. However, in 2012, the left corn cob residue treatment showed a higher MWD compared to control treatment. Overall, a decrease in MWD was observed at each corn cob residue treatment in 2011compared to 2012, especially for the control treatment, where MWD decreased by 0.48 mm and 0.16 mm in clean residue and residue left treatments, respectively.

The statistical analysis of aggregate associated C content showed an interaction effect between aggregate size fraction and corn cob residue treatments in 2011 and 2012, but no differences were observed due to N fertilizer rate (p=0.7145 and p=0.2294 for 2011 and 2012, respectively). Thus an average across N fertilizer rates was used in Fig. 3.26. In general, no differences were observed in aggregate associated C content across corn cob residue treatments within each size fraction in both years. An average of aggregate associated C content across corn cob residue treatments for macro-aggregates was 3.27 g C kg^{-1}, while micro-aggregates was 3.44 g C kg^{-1}. In 2012, the aggregates associated C content decreased by 0.79 g C kg^{-1} in macro-aggregates and increased by 0.28 g C kg^{-1} in micro-aggregates. The reduction in C content in macro-aggregates and increase in micro-aggregates C can be attributed to the tillage system (CT) destruction of macro-aggregates, which are most susceptible to soil disturbance (Six et al., 1999) and machinery traffic (Horn et al., 1995).

Soil bulk density and soil penetration resistance

Soil bulk density (ρ_b) was especially important to measure in areas where corn cob residue bales are stored over the winter. After two years of field experiment at the ENW site, no differences in ρ_b were observed due to years and N fertilizer rates (p=0.1037) . Therefore, an average of ρ_b across these parameters is presented in Fig. 3.27. Generally, corn cob residue treatments showed no effects on ρ_b within each soil depth. However, at the top 0-7.5 cm soil depth, ρ_b was lower compared to that at the 7.5-15 cm and 15-30 cm soil depths across all corn cob residue treatments. The increase in ρ_b at lower soil depths can be a result of soil compaction in areas affected by wheel traffic (Hanna and Al-Kaisi, 2009).

Soil penetration resistance (SPR) was measured after the removal of bales in the spring of 2011 and 2012. The relationship between SPR and soil depth across corn cob residue treatments in both years are presented in Fig. 3.28. In 2011, across corn cob residue treatments SPR showed no differences at the top 40 cm of the soil profile. However, at soil depths below 40 cm, left corn cob residue treatments showed greater SPR values compared to control and clean residue treatments. In 2012, SPR values increased at the clean and left residue treatments compared to the control corn cob residue treatments at the top 35 cm soil depth. In general, soil depths below 35 cm showed higher SPR values for plots where residue left compared to the control and clean corn cob treatments. The increase in SPR values through the whole 60 cm depth in 2012 at the clean and removed corn cob bales treatments can be attributed to heavy traffic of machinery used for removal of corn cob bales and wet soil condition (Hamza and Anderson, 2005).

CONCLUSIONS

After two years of evaluating loose corn cob and corn cob-residue mix bales field application and storage with suite of management practices, including tillage and N fertilization, the following conclusions and recommendations can be made based on the field findings from two sites studies.

Loose corn sobs study experiment (AC site)

After two years of field study applying different amounts of corn cob residue with two tillage systems (CT and NT), and three N fertilizer rates (0, 180, and 270 kg N ha^{-1}), a positive change in SOC and STN contents was observed for all corn cob treatments at the top 0-7.5cm soil depth, but the change in SOC and STN contents at the 15-30 cm depth was negative. This suggests that increasing corn cob residue at the soil surface contributes to the building of soil organic matter and reduction in organic matter mineralization at the top 0-7.5 cm depth. Along with changes in soil C and N; soil pH was affected by tillage, corn cob residue, and N fertilization within each soil depth. The N fertilizer rate of 270 kg N ha^{-1} rate lowered soil pH compared with the 0 and 180 kg N ha^{-1} rates in the CT system. In the NT system, no differences in soil pH were observed for all N fertilizer rates. However, soil pH of CT with 180 kg N ha^{-1} rate was higher compared with soil pH of NT of the same N fertilizer rate and pH of NT and CT with 270 kg N ha^{-1}. Soil spatial variability within plots and potential non-uniformity of N fertilizer application may attribute to the high variability in soil pH values across all corn cob residue treatments.

Changes in MBC values were affected at different times in the growing season by corn cob residue treatments. The highest soil MBC concentration was observed at the 2.5 cm and 7.5 cm corn cob residue treatments, especially in June and July (mid-summer) compared to the control and removed corn cob residue treatments. Also, soil organic acids concentrations of oxalic and butyric were the most detectable in the soil with all residue treatments in 2011 only. The concentrations of these two organic acids were highly affected by time of the year (spring vs. fall), moisture conditions, and residue treatments, where control and removed residue treatments had greater concentrations compared with the 7.5 cm residue treatment in 2011.

In both years corn cob residue treatments show no effect on WSA percentage. However, after two years findings showed that soil macro-aggregates fractions across all corn cob residue treatments had a decrease in percentages of stability and associated C content, while there is an increase in soil micro-aggregates percentages of stability and associated C content. The reduction in soil macro-aggregates percent of WSA and associated C content by the end of the study can be due to the machinery traffic and changes in soil conditions (wetting and drying). In general, the findings show that tillage system (CT and NT) had limited effects on WSA in the short time of managing different corn cob residue treatments. Also, N application as a mitigating practice for corn cob residue show limited effect in improving soil aggregates as reflected by MWD values.

High amounts of corn cob residue left on the soil surface as with 7.5 cm caused a decrease in ρ_b than other residue treatments across all soil depths and years. The finding revealed that the complete removal of corn cob residue from the field, regardless of the tillage system caused an increase in SPR when compared to 2.5 and 7.5 cm corn cob residue treatments throughout the soil profile. However, these differences in SPR between corn cob residue treatments disappeared by the end of the second year. Residue clean up and corn cob removal caused an increase in SPR, ρ_b, and reduction in WSA when such management practices conducted in the same field on yearly basis. Another parameter affected by corn cob removal is I_r. The different N application has little effect in improving I_r, but the increase of residue level left on the soil surface contributes to the increase in I_r, especially with CT system. These findings indicate that tillage along with high amount of residue can improve initial I_r. However, regardless of the amount of corn cob residue left on the soil surface, NT system showed no change in I_r.

The loose corn cob residue left after corn cob piles removal should be managed carefully. The findings of this study document that the process of corn cob residue cleans up can affect certain soil health parameters, especially ρ_b, SPR, WSA, and I_r. Such negative effects are associated with machinery use and equipment traffic in wet condition. These negative effects can be mitigated by avoiding random traffic on the field, wet soil condition, and storage of corn cob in a designated area at the edge of the field. Changes in soil health due to practices of managing corn cob residue were also reflected in changes in SOC content with the increase in the amount of corn cob residue left on the soil surface, which can have positive effect on increasing SOC concentration. The combination of proper tillage, N fertilizer, and traffic control can be effective practices in mitigating potential negative effect on soil health. Thus storage and removal of corn cob residue needs to be managed with caution in order to control soil compaction and excessive amounts of loose corn cob residue left on the soil surface, which can affect soil health parameter.

Corn cob bales experiment (ENW site)

After two years of storage of corn cob bales at the ENW site, some changes in the SOC and STN contents were observed from 2010 to 2012 at different soil depths. Corn cob residue treatments and N fertilizer rates show no effects on SOC and STN contents. Most improvement in SOC and STN contents were observed at the top 7.5 cm soil depth with some exceptions at lower depths. Declines in SOC and STN contents associated with bales treatments was mainly due to tillage system (CT) and soil erosion, especially where soil compaction caused by machinery traffic, during the removal of corn cob bales. Residue treatments and removal of bales and N fertilizer rate have minimum effect on changing soil pH values over two years of bales treatments. Another indicator for soil health is MBC concentration, which measures the dissolved carbon present in microbial community in soil. In general, there was no corn cob residue effect on MBC observed within each soil sampling period for both years. Greater MBC values were observed in the fall for both years across all corn cob residue treatments than early spring. The increase in MBC concentrations can be due to the increase in organic matter and its decomposition when left on the soil surface after harvest and after the removal of corn cob bales. Therefore, residue left on the soil surface during bales removal can have positive effect on improving soil C pool and eventually improves other soil properties.

The N fertilization rates show limited effects on water stable aggregates (WSA) and their associated C content. However, soil macro-aggregates stability and associated C content across all corn cob residue treatments showed a decline by the end of the experiment, while they increased for micro-aggregates. The reduction of soil macro-aggregates stability was also observed as indicated by MWD decline over time across all corn cob residue treatments. Even though corn cob residue treatments had no effect on WSA, it was noticed that the reduction in macro-aggregates can be caused by tillage disturbance and machinery traffic during bales removal. Changes in ρ_b were mostly found at the top 7.5 cm soil profile, across all corn cob residue treatments, which are consistent with the increase in SPR values in the same depth. The greatest SPR values are observed in areas where corn cob bales were stored. The machinery traffic for removing the corn cob bales caused the increase in SPR with increase in soil depth. The combination of equipment traffic and wet condition during the removal of corn cob residue bales was the main factor in causing soil compaction. Therefore, managing bales collection and removal should be approached carefully by considering traffic control, field moisture conditions, area of bales storage in the field, and tillage system. It's essential that proper timing of entering the field, dry soil conditions, and management of machinery traffic should be implemented during the removal of corn cob bales.

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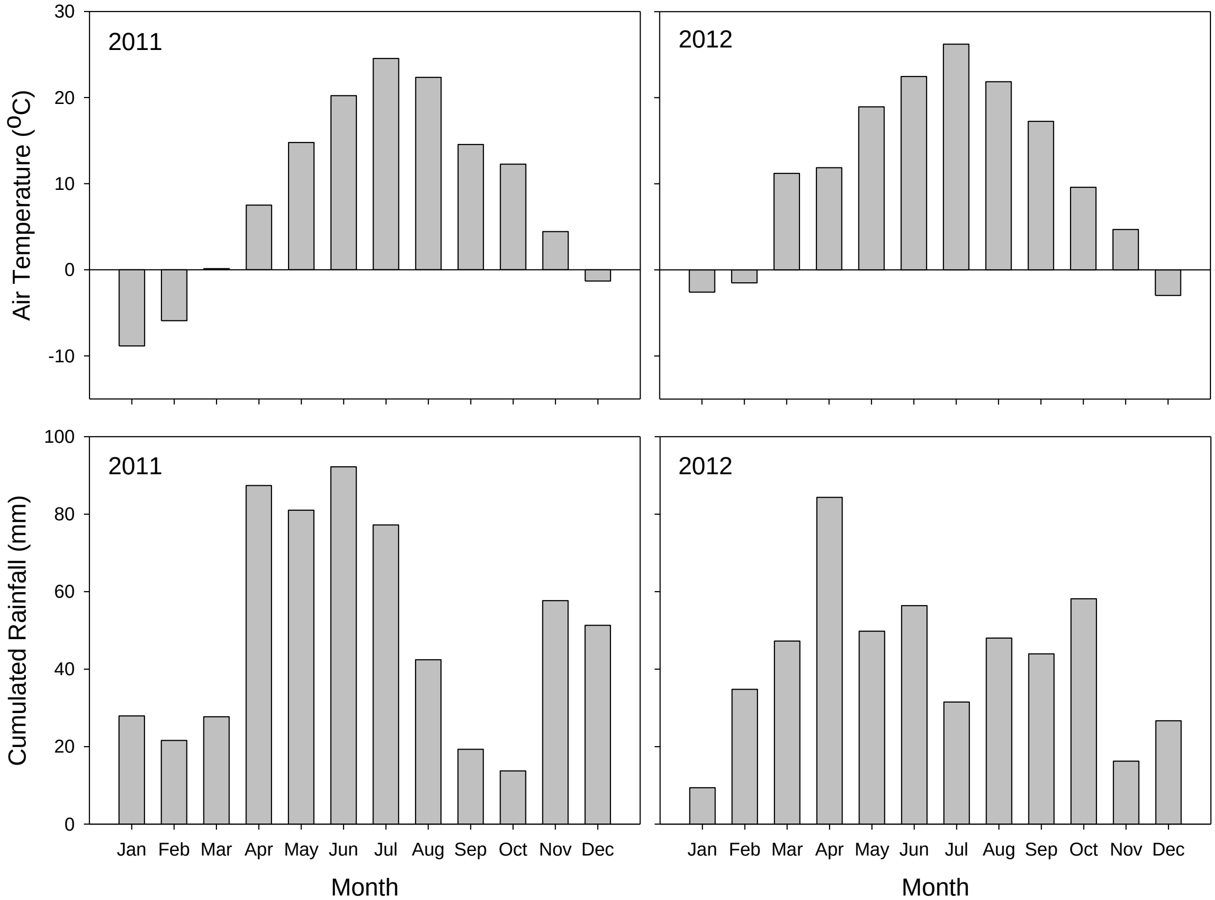

Figure 3.1. Average monthly air temperature and rainfall by years (2011 and 2012) in Ames central site (AC)

Figure 3.2. Corn cob pile and corn cob residue effect on plant growth in 2009-2010 at Emmetsburg, IA.

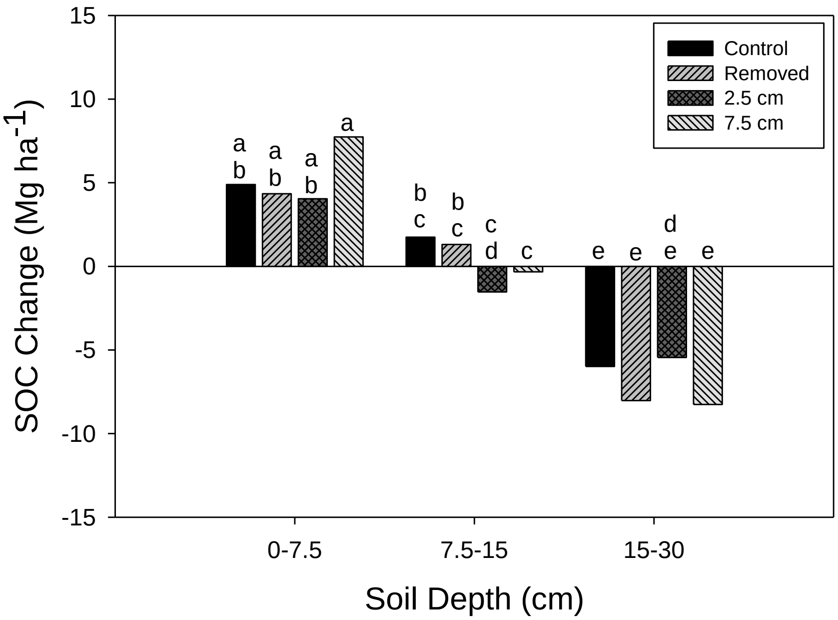

Figure 3.3. Corn cob residue effects on soil organic carbon content change across tillage system and nitrogen fertilizer rates from 2010 to 2012 by soil depths in Ames Central site (AC). Means with the same letter across corn cob residue and soil depth are not significantly different at $p \leq 0.05$.

Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.

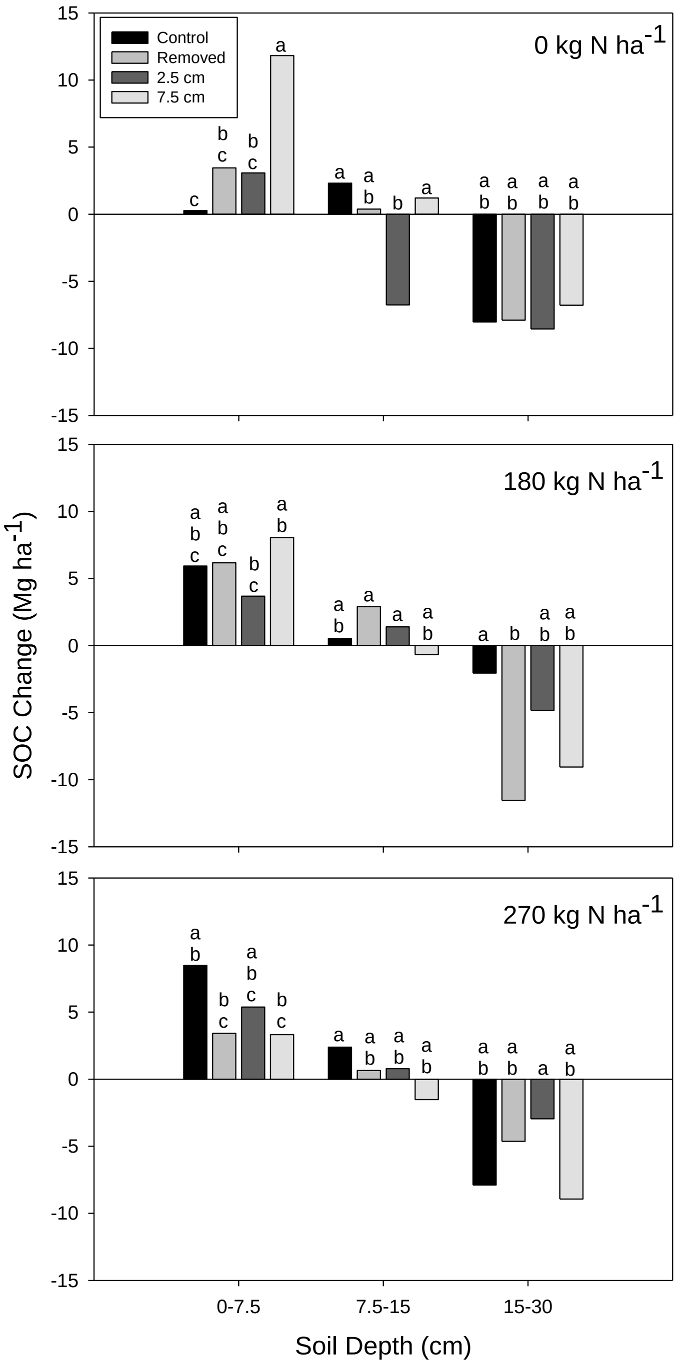

Figure 3.4. Corn cob residue effects on soil organic carbon content change across tillage system from 2010 to 2012 by nitrogen fertilizer rate and soil depths in Ames Central site (AC). Means with the same letter across corn cob residue and nitrogen fertilizer rates within each soil depth are not significantly different at $p \leq 0.05$.

Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.

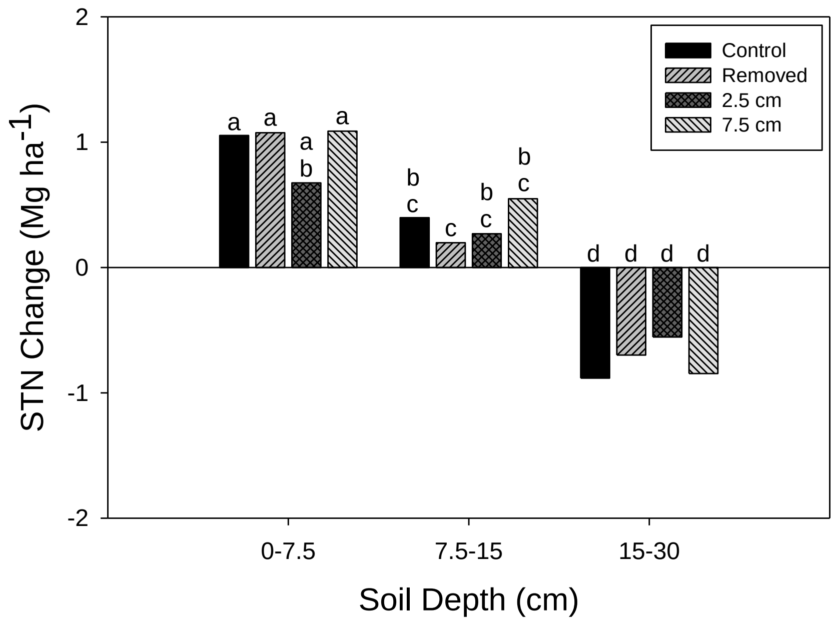

Figure 3.5. Corn cob residue effects on soil total nitrogen content change across tillage system and nitrogen fertilizer rates from 2010 to 2012 by soil depths in Ames Central site (AC). Means with the same letter across corn cob residue and soil depth are not significantly different at $p \leq 0.05$.

Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.

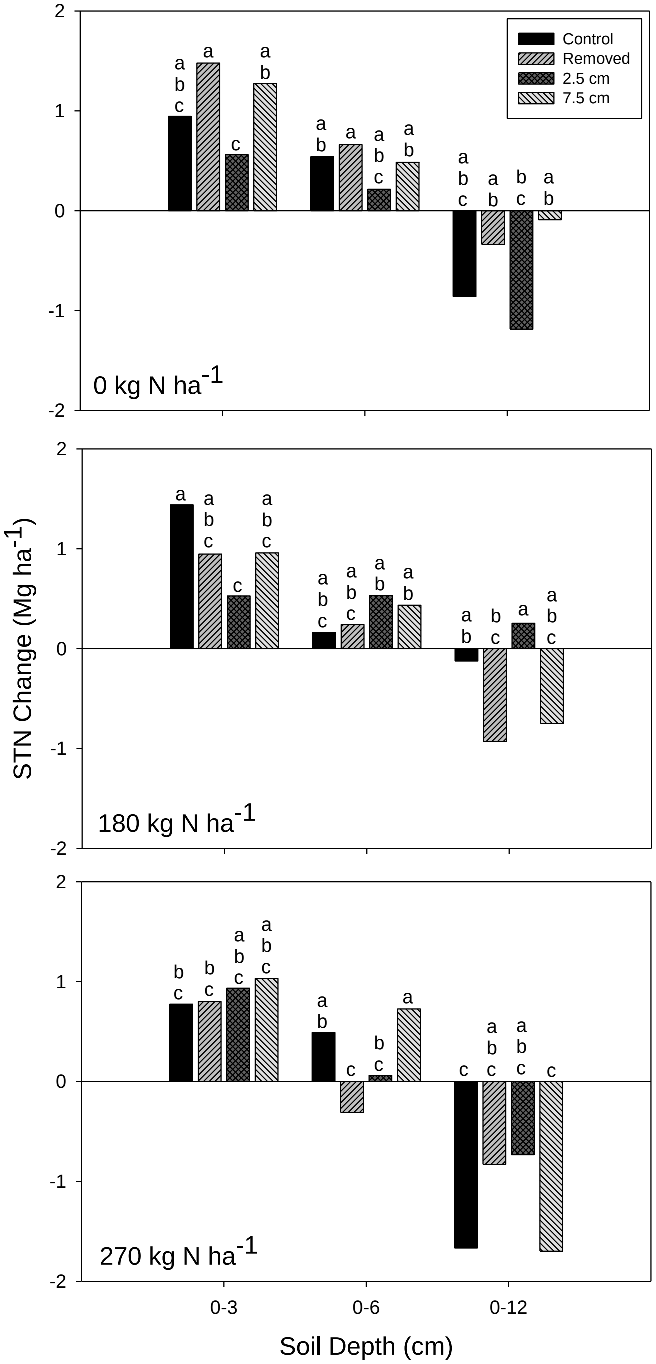

Figure 3.6. Corn cob residue effects on soil total nitrogen content change across tillage system from 2010 to 2012 by nitrogen fertilizer rates and soil depths in Ames Central site (AC). Means with the same letter across corn cob residue and nitrogen fertilizer rates within each soil depth are not significantly different at $p \leq 0.05$.

Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.

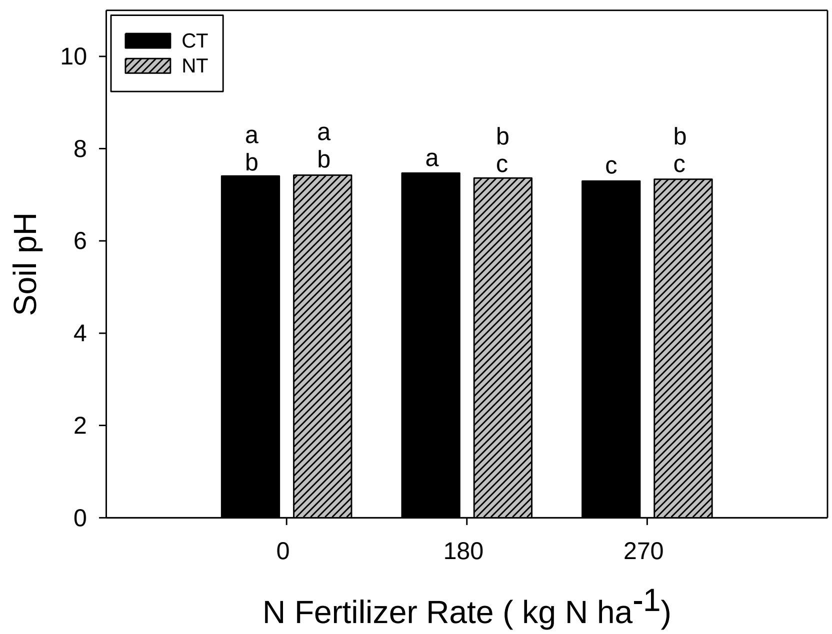

Figure 3.7. Tillage system effects on soil pH across corn cob residue, year, and soil depths by nitrogen fertilizer rates in Ames Central site (AC). Means with the same letter across nitrogen fertilizer rates and tillage system are not significantly different at $p \leq 0.05$.

CT is conventional tillage; NT is no-till.

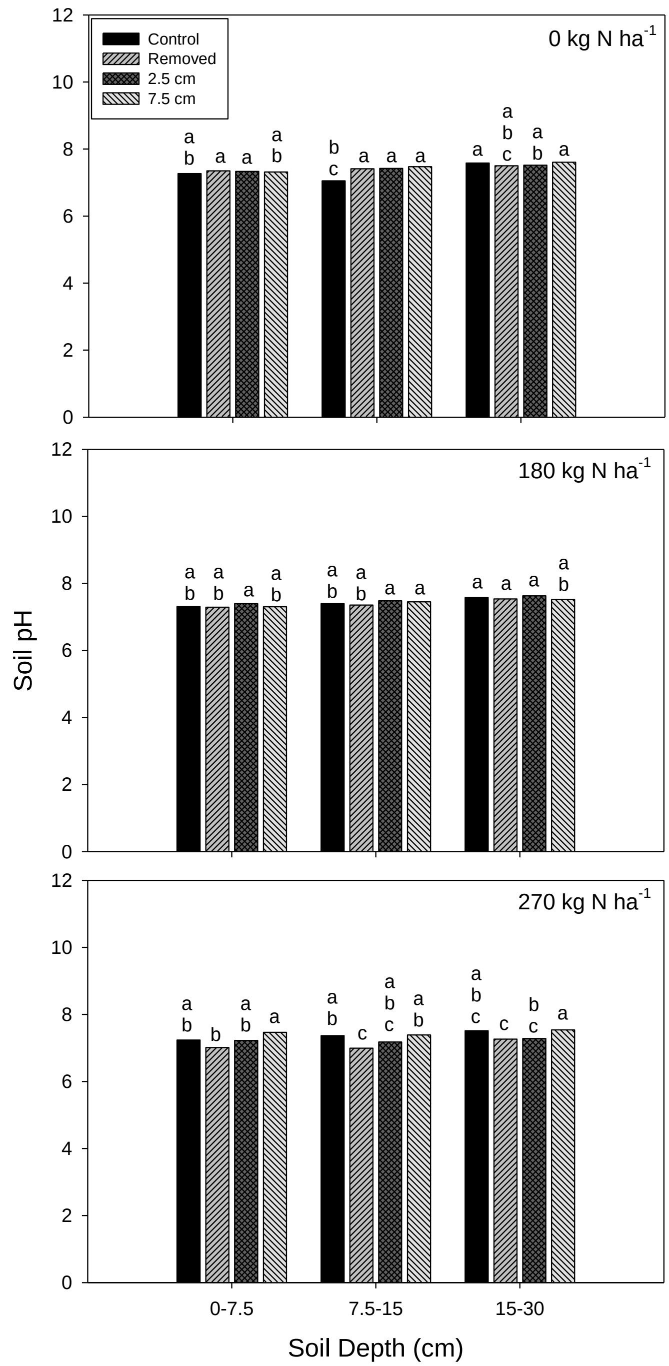

Figure 3.8. Corn cob residue effects on soil pH across tillage system and year by nitrogen fertilizer rates and soil depths in Ames Central site (AC). Means with the same letter across corn cob residue and nitrogen fertilizer within each soil depths are not significantly different at $p \leq 0.05$.

Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.

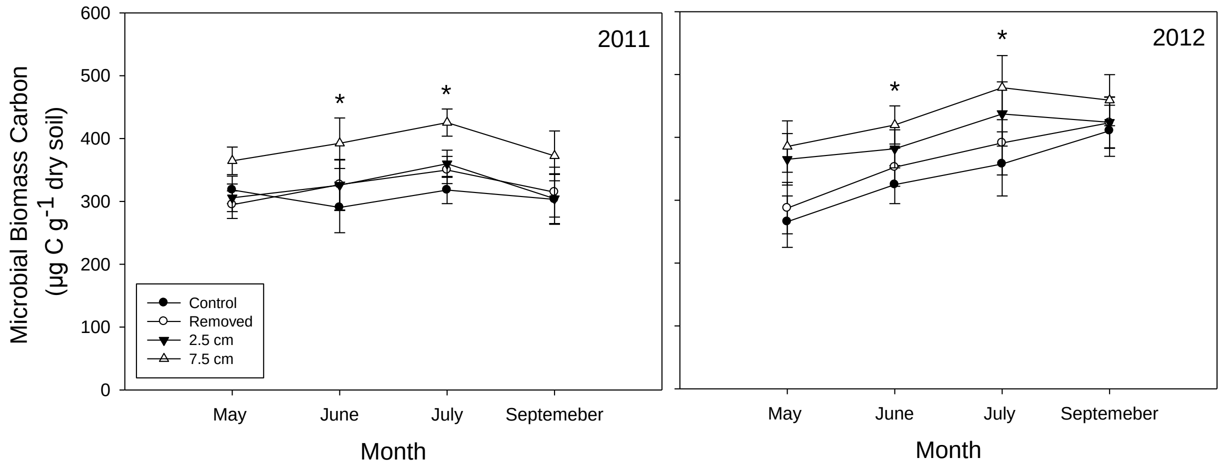

Figure 3.9. Corn cob residue effects on microbial biomass carbon at 15 cm across tillage system and nitrogen fertilizer rates throughout summer for 2011 and 2012 in Ames Central site (AC). A significant deference across corn cob residue treatments within each month is noted with an asterisk (*) at p≤ 0.05.

Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.

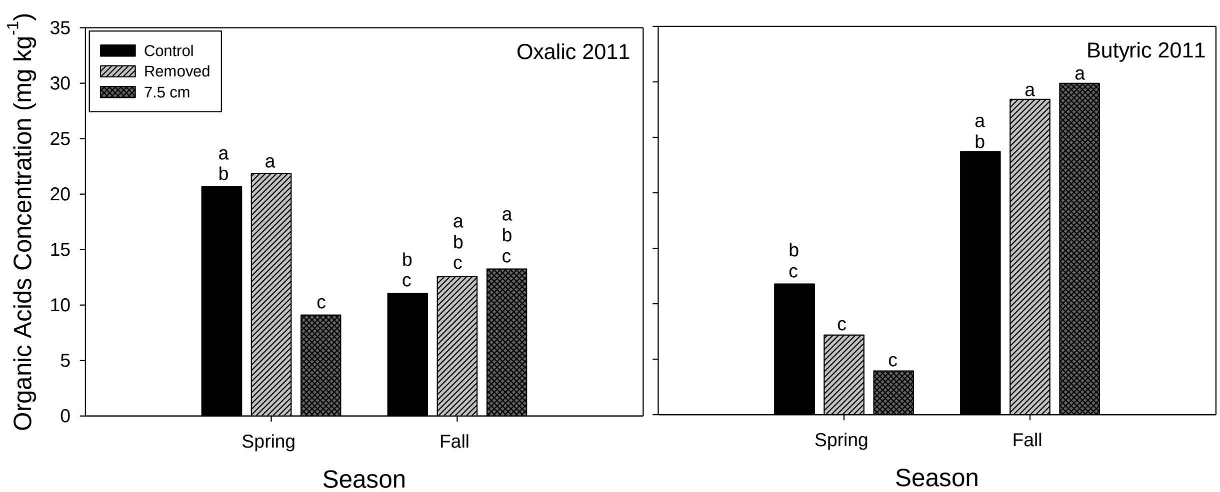

Figure 3.10. Corn cob residue effects on soil oxalic and butyric organic acids across tillage system for 2011 in Ames Central site (AC). Means with the same letter across corn cob residue and season are not significantly different at p ≤ 0.05.

Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
7.5 cm is corn cob residue depth applied.

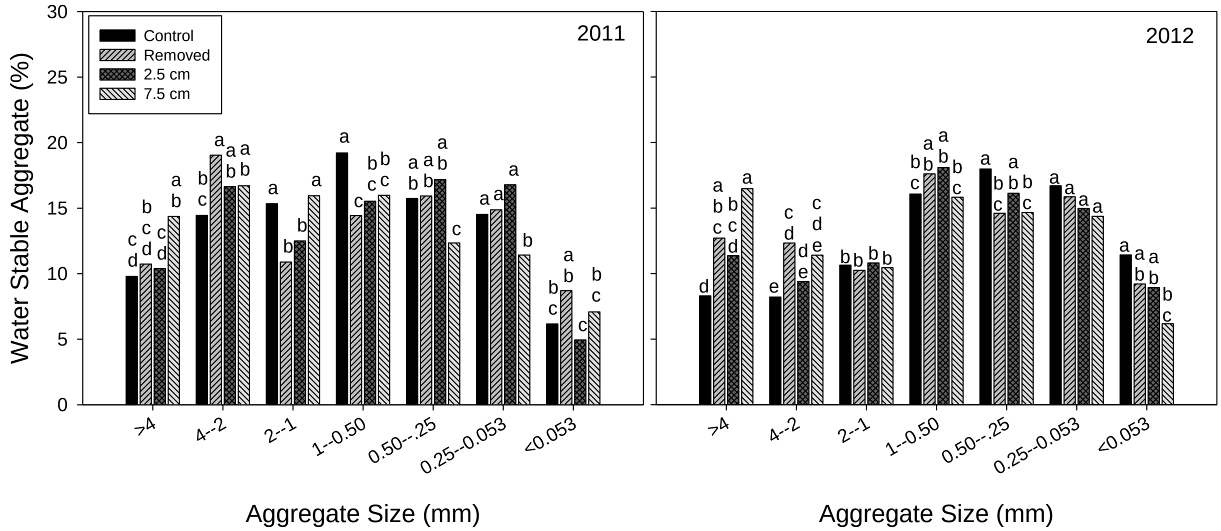

Figure 3.11. Corn cob residue effects on water stable aggregates distribution across tillage system and nitrogen fertilizer rates by size fraction for 2011 and 2012 in Ames Central site (AC). Means with the same letter across corn cob residue and year within each size fraction are not significantly different at $p \leq 0.05$.

Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.

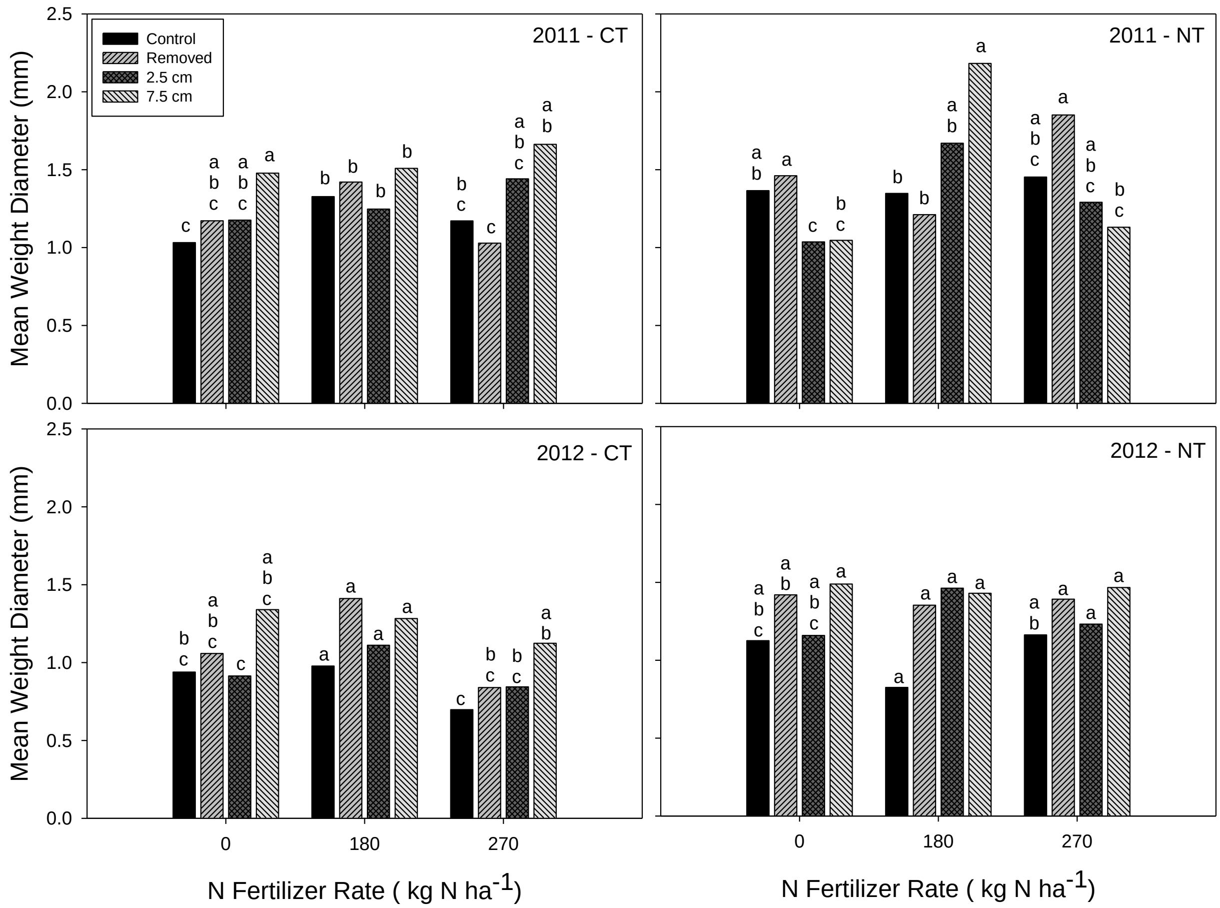

Figure 3.12. Corn cob residue effects on mean weight diameter of aggregates for 2011 and 2012 in Ames Central site (AC). Means with the same letter across corn cob residue and tillage system within each nitrogen fertilizer rate and year are not significantly different at $p \leq 0.05$.

Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.
CT is conventional tillage; NT is no-till.

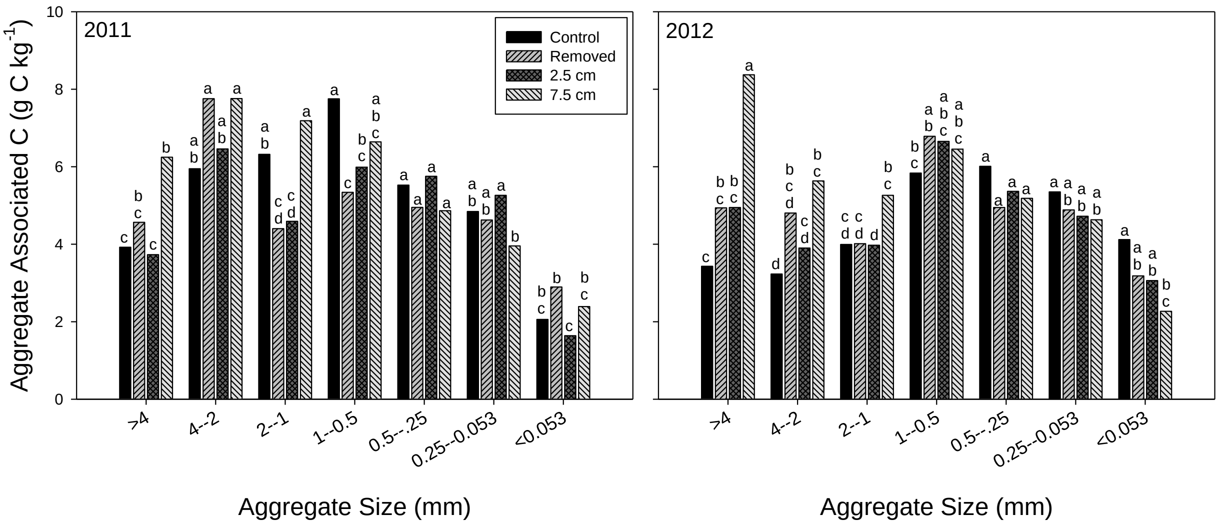

Figure 3.13. Corn cob residue effects on aggregates associated carbon content distribution across tillage system and nitrogen fertilizer rates by size fraction for 2011 and 2012 in Ames Central site (AC). Means with the same letter across corn cob residue and year within each size fraction are not significantly different at p ≤ 0.05.

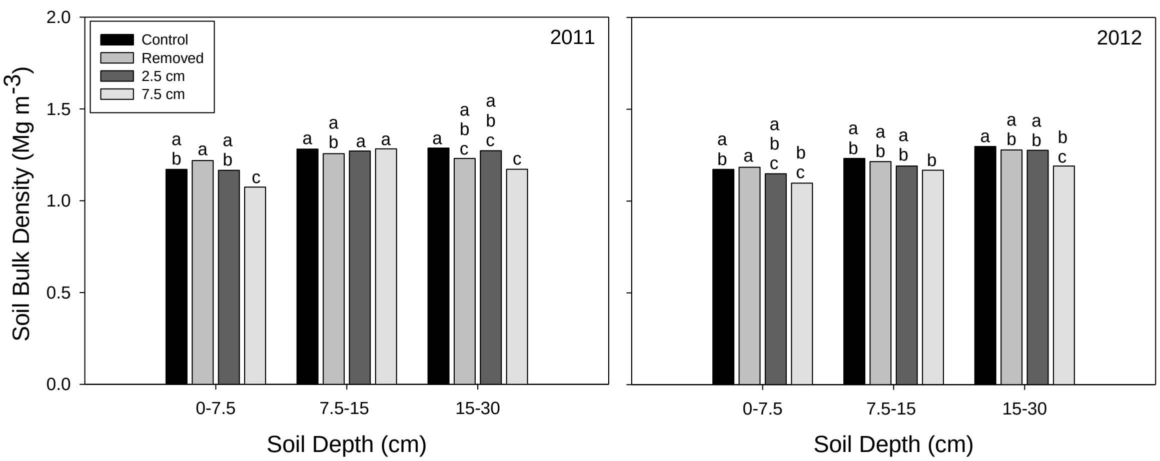

Figure 3.14. Corn cob residue effects on soil bulk density across tillage and nitrogen fertilizer rates by soil depths for 2011and 2012 in Ames Central site (AC). Means with the same letter across corn cob residue within each soil depths and year are not significantly different at p ≤ 0.05.

Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.

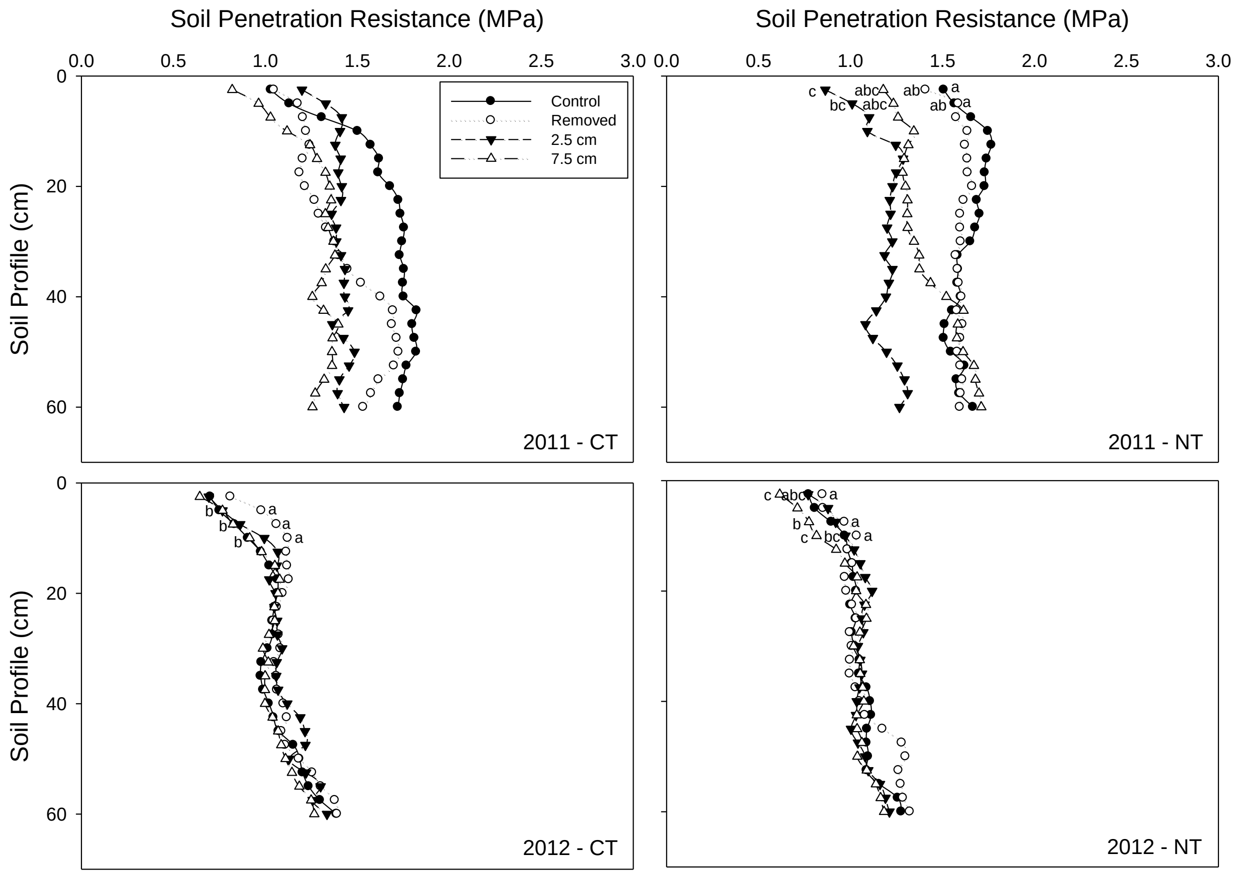

Figure 3.15. Corn cob residue effect on soil penetration resistance by soil profile and tillage system for 2011 and 2012 in Ames Central site (AC). Means with the same letter across corn cob residue and tillage system within each soil depth are not significantly different at $p \leq 0.05$.

Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.
CT is conventional tillage; NT is no-till.

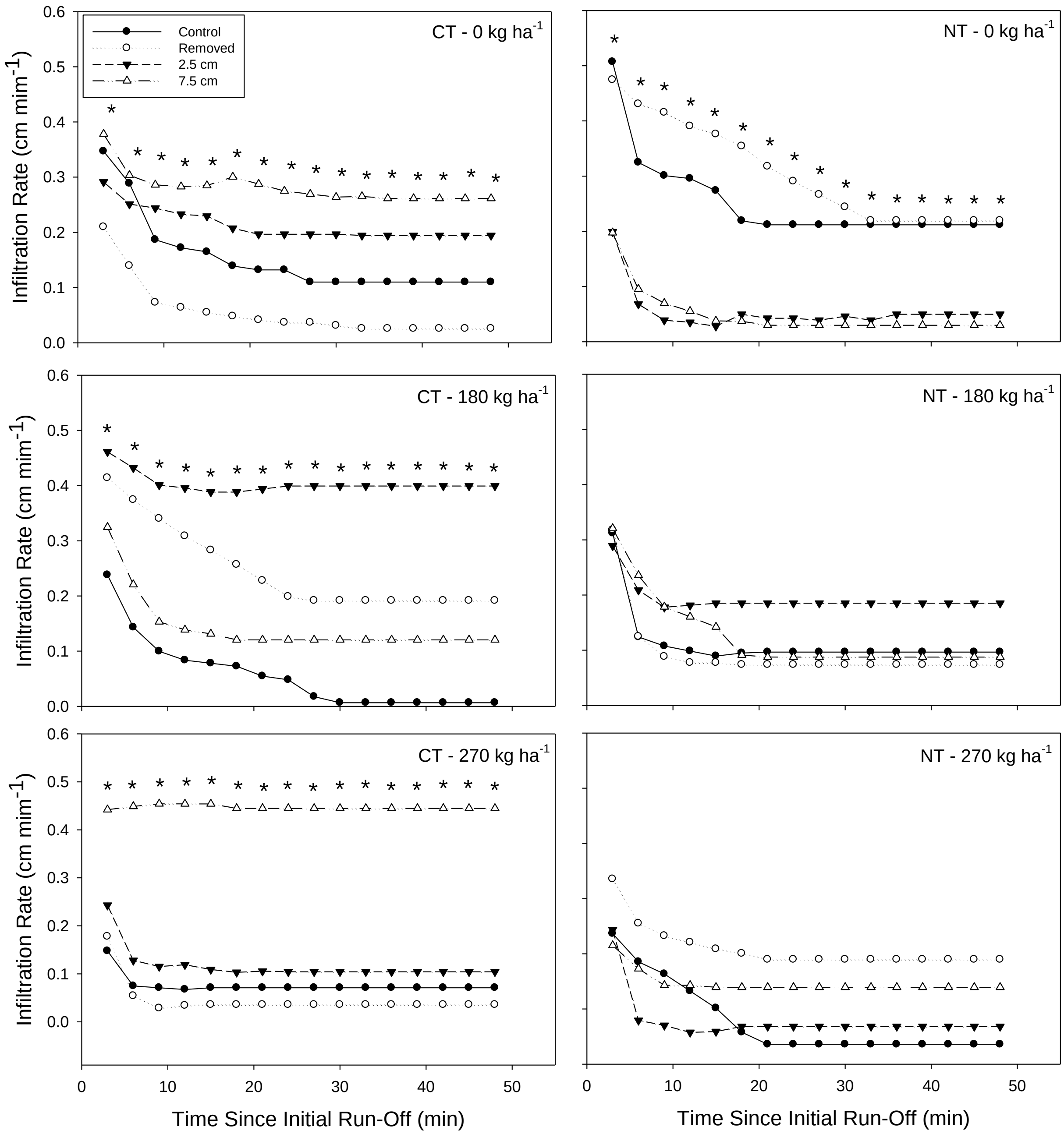

Figure 3.16. Corn cob residue effect on water infiltration rate by tillage system and nitrogen fertilizer rates for 2012 in Ames Central site (AC). A significant difference across corn cob residue treatments within each nitrogen fertilizer rates and tillage system for each time is noted with an asterisk (*) at p≤ 0.05.

Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.
CT is conventional tillage; NT is no-till.

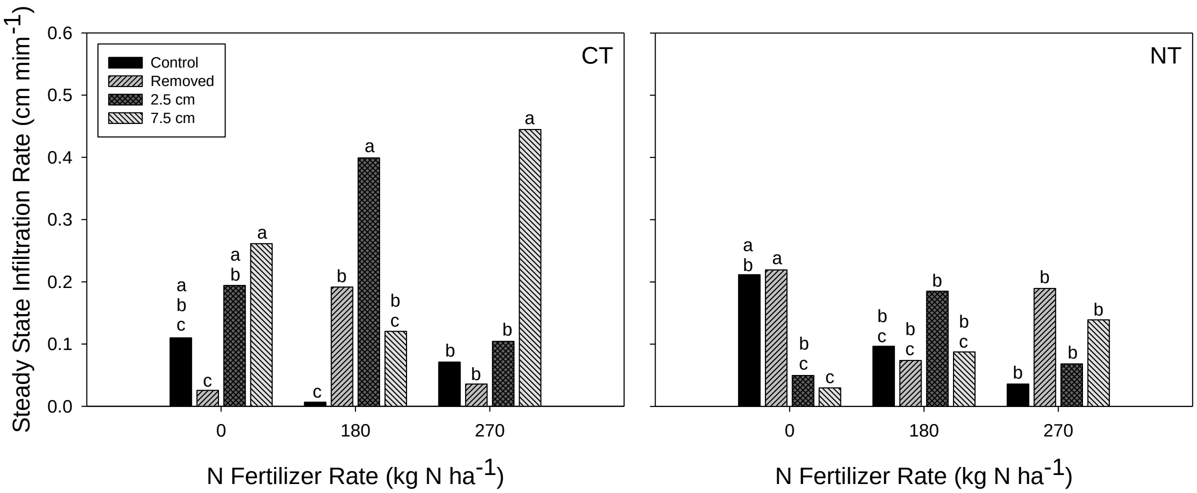

Figure 3.17. Corn cob residue effects on steady state infiltration rate by tillage system and nitrogen fertilizer rates for 2012 in Ames Central site (AC). Means with the same letter across corn cob residue and tillage system within each nitrogen fertilizer rate are not significantly different at $p \leq 0.05$.

Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.
CT is conventional tillage; NT is no-till.

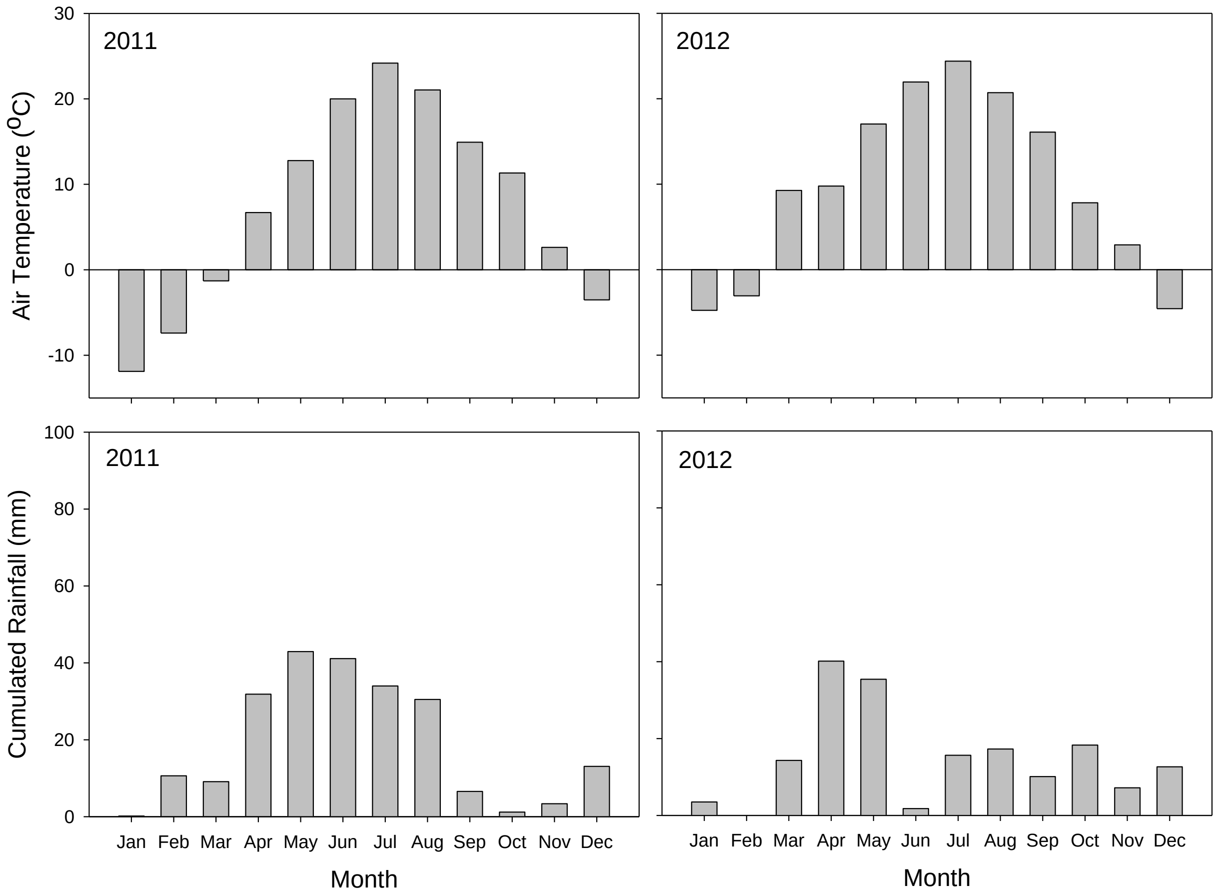

Figure 3.18. Average monthly air temperature and rainfall by years (2011 and 2012) in Emmetsburg Northwest site (ENW).

Figure 3.19. Corn cob bales placement after harvest in 2011 at Emmetsburg Northwest site (ENW).

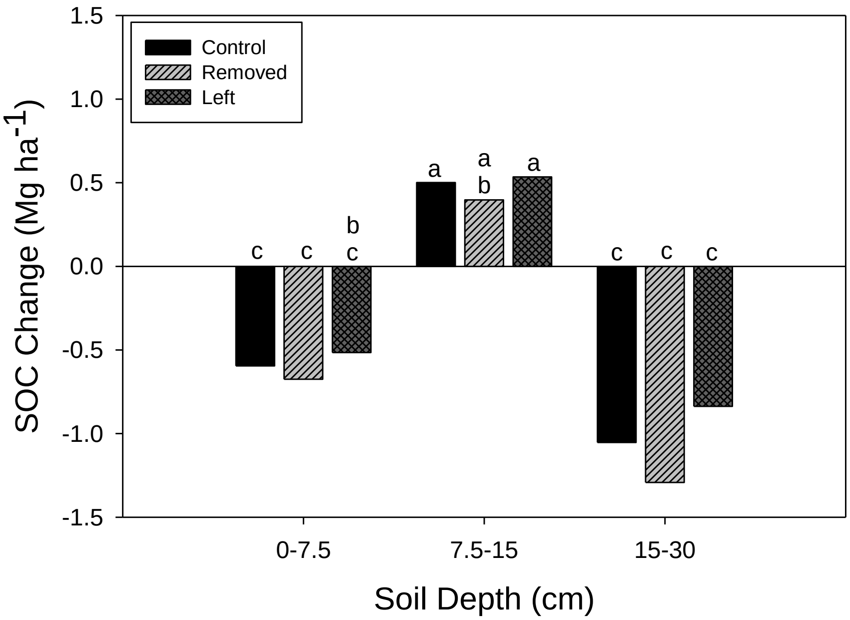

Figure 3.20. Corn cob residue effects on soil organic carbon content change across nitrogen fertilizer rates from 2010 to 2012 by soil depths in Emmetsburg Northwest site (ENW). Means with the same letter across corn cob residue and soil depth are not significantly different at $p \leq 0.05$.

Control is treatment where no bales were placed on plot
Removed is corn cob and other residue were completely removed from each plot after bale storage
Left is corn cob residue on soil surface after bale removal as results of bales breakdown during the removal process if any.

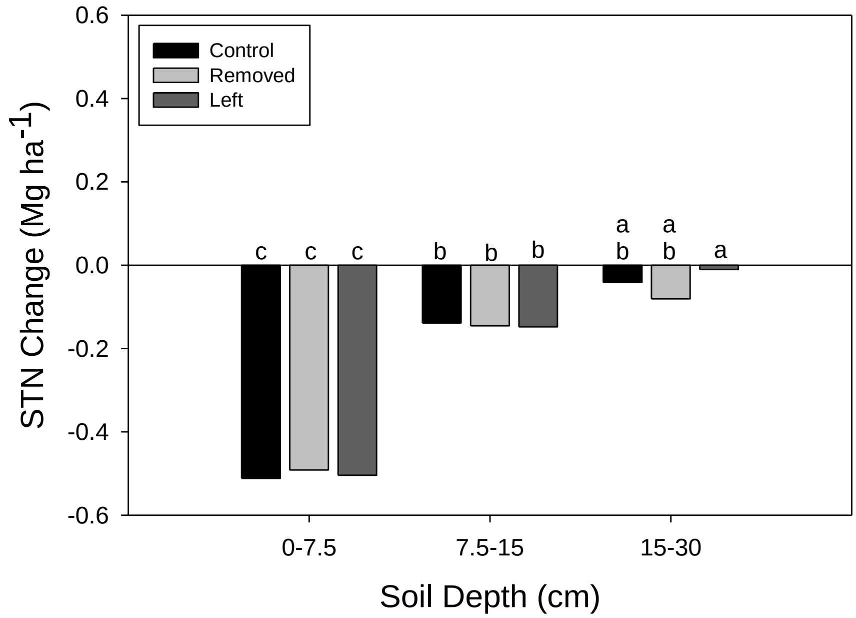

Figure 3.21. Corn cob residue effects on soil total nitrogen content change across nitrogen fertilizer rates from 2010 to 2012 by soil depths in Emmetsburg Northwest site (ENW). Means with the same letter across corn cob residue and soil depth are not significantly different at $p \leq 0.05$.

Control is treatment where no bales were placed on plot
Removed is corn cob and other residue were completely removed from each plot after bale storage
Left is corn cob residue on soil surface after bale removal as results of bales breakdown during the removal process if any.

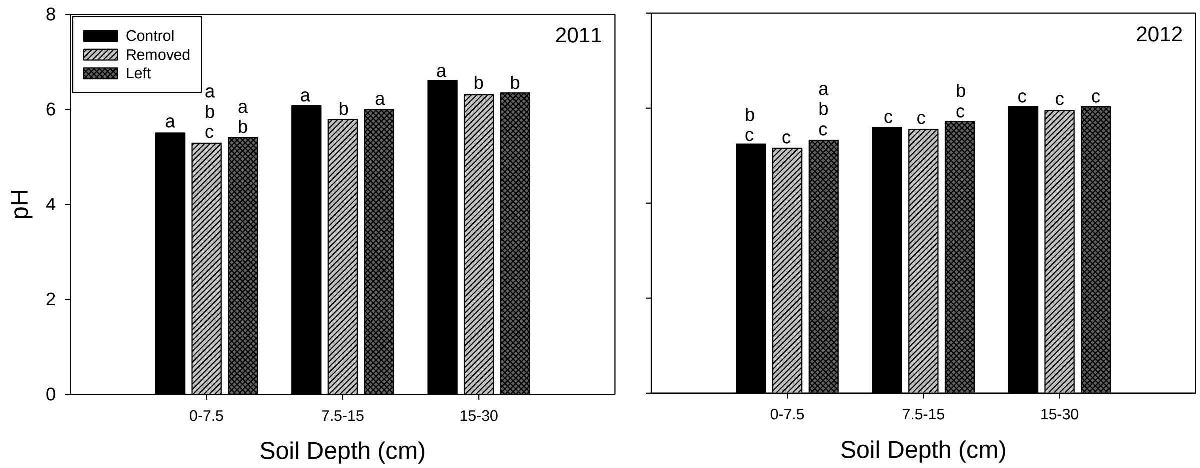

Figure 3.22. Corn cob residue effects on soil pH across nitrogen fertilizer rates by soil depths for 2011 and 2012 in Emmetsburg Northwest site (ENW). Means with the same letter across corn cob residue and year within each soil depth are not significantly different at $p \leq 0.05$.

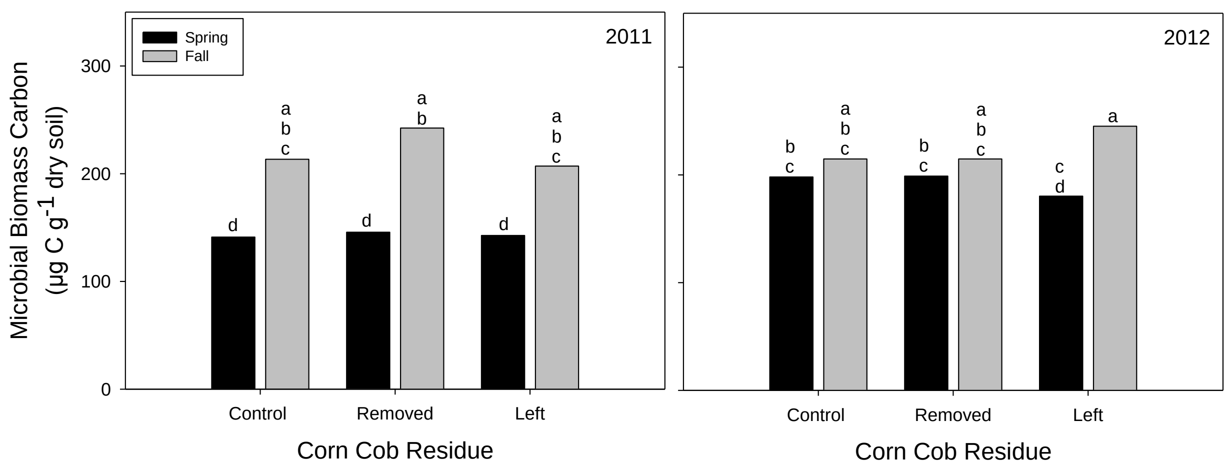

Figure 3.23. Corn cob residue effects on microbial biomass carbon across nitrogen fertilizer rates at fall and spring for 2011 and 2012 in Emmetsburg Northwest site (ENW). Means with the same letter across corn cob residue, seasons (spring and fall) and year are not significantly different at $p \leq 0.05$.

Control is treatment where no bales were placed on plot
Removed is corn cob and other residue were completely removed from each plot after bale storage
Left is corn cob residue on soil surface after bale removal as results of bales breakdown during the removal process if any.

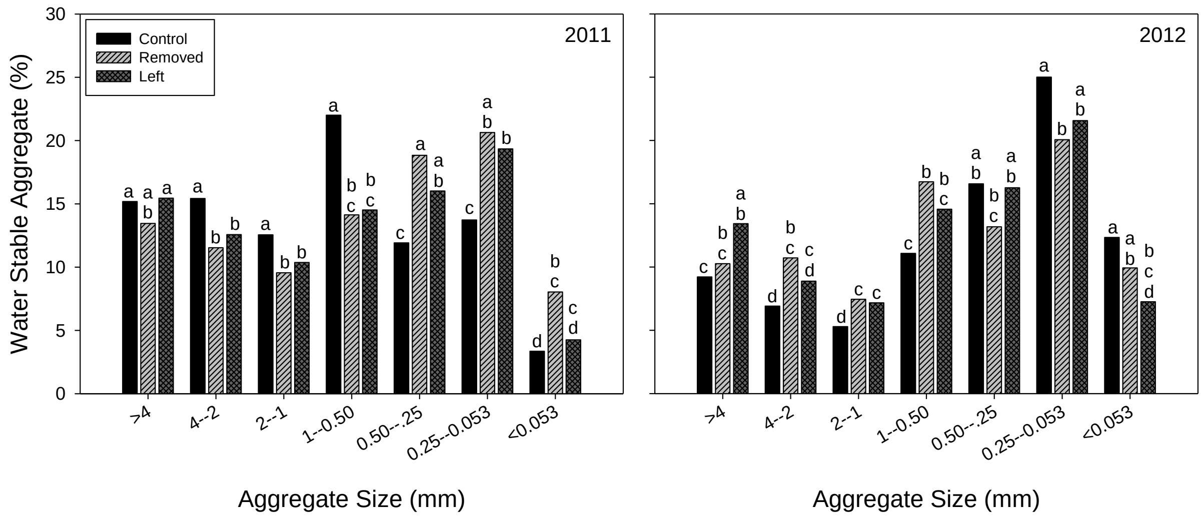

Figure 3.24. Corn cob residue effects on water stable aggregates distribution across nitrogen fertilizer rates for 2011 and 2012 in Emmetsburg Northwest site (ENW). Means with the same letter across corn cob residue and year within each size fraction are not significantly different at $p \leq 0.05$.

Control is treatment where no bales were placed on plot
Removed is corn cob and other residue were completely removed from each plot after bale storage
Left is corn cob residue on soil surface after bale removal as results of bales breakdown during the removal process if any.

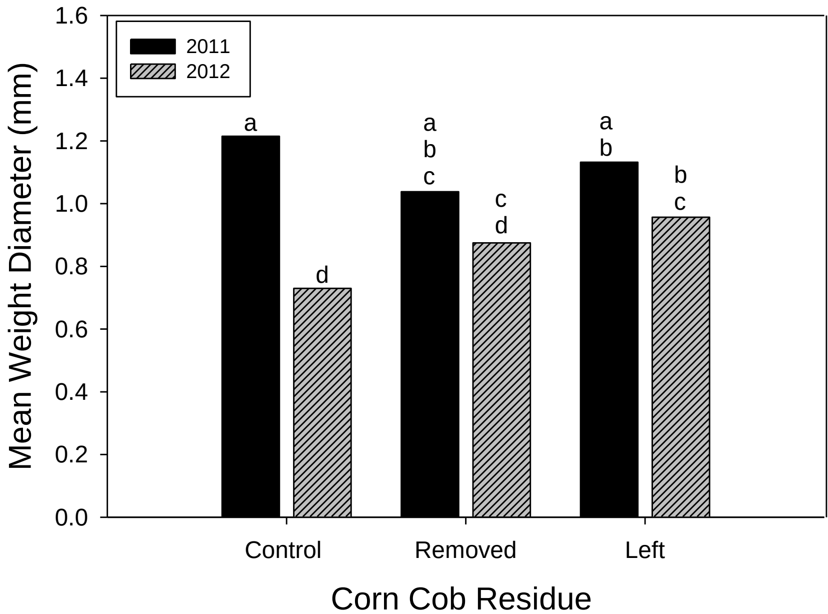

Figure 3.25. Corn cob residue effects on mean weight diameter of aggregates across nitrogen fertilizer rates for 2011 and 2012 in Emmetsburg Northwest site (ENW). Means with the same letter across corn cob residue and year are not significantly different at $p \leq 0.05$.

Control is treatment where no bales were placed on plot
Removed is corn cob and other residue were completely removed from each plot after bale storage
Left is corn cob residue on soil surface after bale removal as results of bales breakdown during the removal process if any.

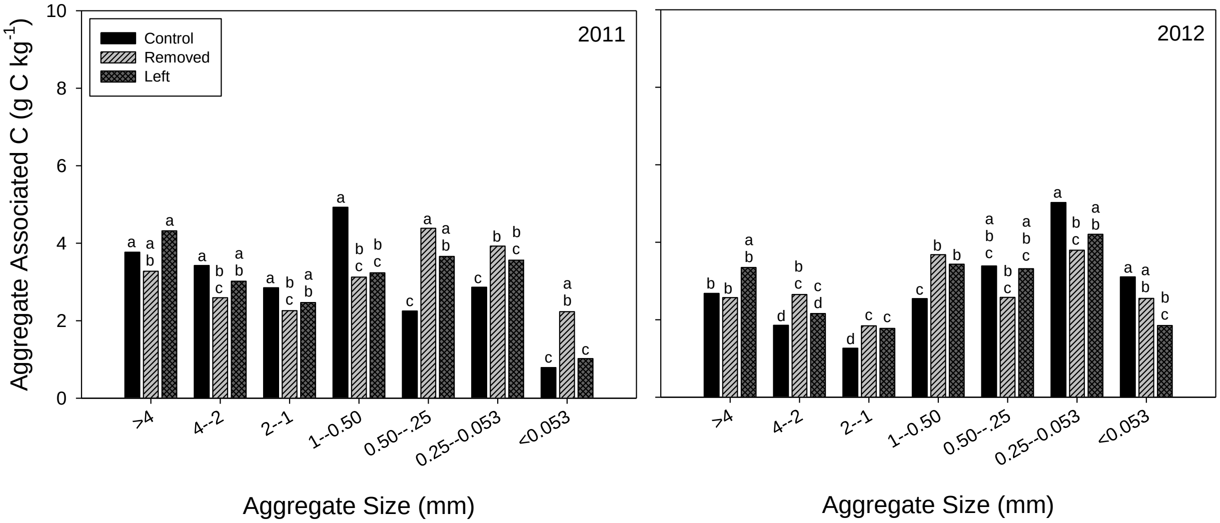

Figure 3.26. Corn cob residue effects on aggregates associated carbon content distribution across nitrogen fertilizer rates for 2011 and 2012 in Emmetsburg Northwest site (ENW). Means with the same letter across corn cob residue and year within each size fraction are not significantly different at $p \leq 0.05$.

Control is treatment where no bales were placed on plot
Removed is corn cob and other residue were completely removed from each plot after bale storage
Left is corn cob residue on soil surface after bale removal as results of bales breakdown during the removal process if any.

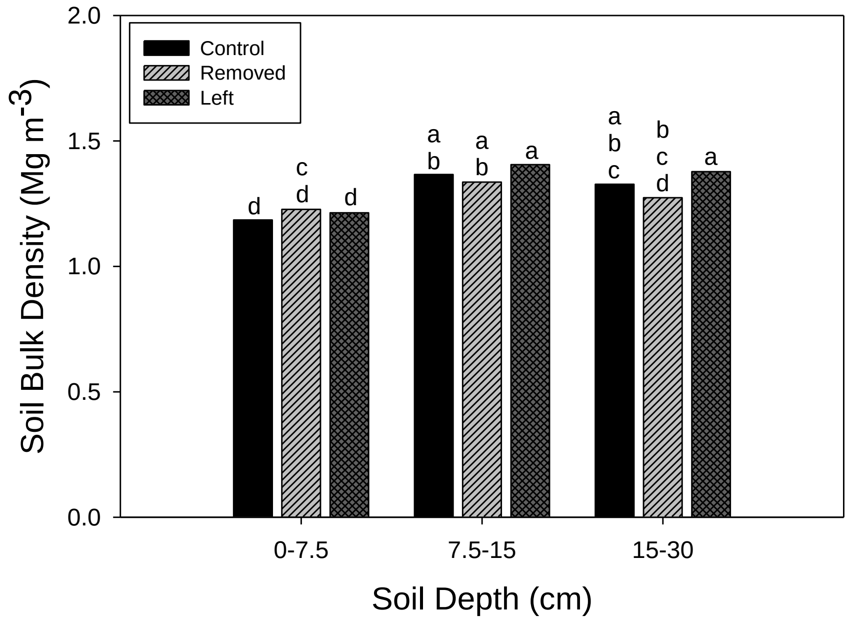

Figure 3.27. Corn cob residue effects on soil bulk density across nitrogen fertilizer rates and year by soil depths in Emmetsburg Northwest site (ENW). Means with the same letter across corn cob residue and soil depths are not significantly different at $p \leq 0.05$.

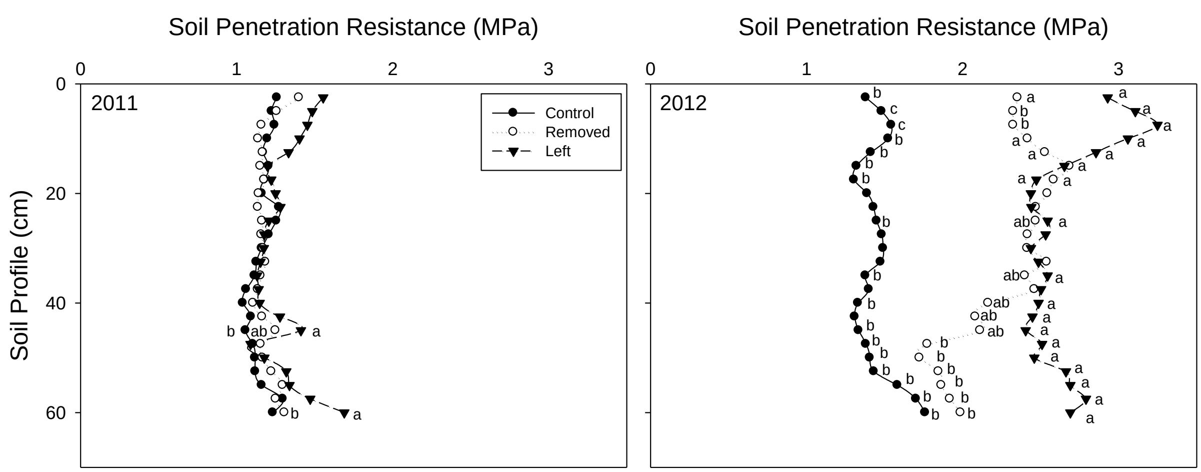

Figure 3.28. Corn cob residue effect on soil penetration resistance through soil profile for 2011 and 2012 in Emmetsburg Northwest (ENW). Means with the same letter across corn cob residue within each soil depth and year are not significantly different at $p \leq 0.05$.

Control is treatment where no bales were placed on plot
Removed is corn cob and other residue were completely removed from each plot after bale storage
Left is corn cob residue on soil surface after bale removal as results of bales breakdown during the removal process if any.

CHAPTER 4

CORN COB RESIDUE MANAGEMENT EFFECT ON GREENHOUSE GAS EMISSION

ABSTRACT

In-field management practices of loose corn cob residue as feedstock source for ethanol production can have potential effects on greenhouse gas emission. The objective of this study was to investigate the effects of loose corn cob residue storage in-field and subsequent removal on soil CO_2 and N_2O emission. The study was conducted in 2010-2012 at the Iowa State University Agronomy Research Farm located near Ames, Iowa. The soil type at the site is Canisteo silty clay loam (Fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls). The treatments of corn cob residue consisted of control, removed residue (7.5 cm applied in the fall and completely removed early spring), 2.5, and 7.5 cm corn cob depths over two tillage systems of no-till (NT) and chisel plow (CT) and three N rates (0, 180, and 270 kg N ha^{-1}) of 32% liquid UAN (NH_4NO_3) in a randomized complete block design with split-split arrangements. The findings of the study suggest that soil CO_2 and N_2O emission increased as the amount of corn cob residue left on the soil surface are increased. It was also observed that corn cob residue treatments affected soil moisture content and soil mineral N concentration. However, CO_2 emission was less affected by N rate as it was with N_2O emission, where high N rate and soil mineral N caused greater soil N_2O emission regardless of the corn cob residue amount left on the soil surface. Also it was observed that NT produced higher CO_2 emission in 2012 than CT with higher amount of corn cob residue left on the soil surface. Additionally no differences in N_2O emission were observed due to tillage system. In general, dry soil condition as in 2012 caused a reduction in both CO_2 and N_2O emission across all tillage, residue treatments, and N

rates. Proper corn cob residue cleanup after corn cob piles removal along with adequate tillage and N management may minimize CO_2 and N_2O emission.

INTRODUCTION

The dependency on fossil fuel in the United States (U.S.) has prompt the use of renewable sources of energy such as biomass, solar, wind, geothermal, etc. Currently in the Midwest, corn (*Zea mays* L.) crop residue has been considered as feedstock for cellulosic ethanol production as an alternative to fossil fuel, which has the potential to reduce greenhouse gas emission (GHG) (Dwivedi et al., 2009; Wilhelm et al., 2004; Graham et al., 2007). The cellulosic ethanol production from corn residue, which is a mixture of corn cob and corn stover (stalks and leaves), has been used currently as feedstock source by ethanol plants in Iowa (Schubert, 2006). However, field observations showed that storage and collection of corn cob residue in the field caused detrimental effects on plant growth and development (personal observations of several fields in northwest Iowa in 2009). Therefore, piling and removal of loose corn cob residue along with associated management practices of tillage and N fertilization can have an effect on potential soil health (Wilhelm et al., 2004; Graham et al., 2007), N immobilization, plant growth, and potential effects on greenhouse gas emission (Chen et al., 2013).

Crop residue plays an important role in improving and maintaining adequate soil physical and chemical properties, which are essential in maintaining soil productivity (Karlen et al., 1994). Therefore, changes in management practices associated with crop residue can contribute to changes in soil environment including GHG emission (CO_2 and N_2O) (Cole et al., 1997; Smith et al., 2007). Some strategies to mitigate GHG emission may include crop rotation, efficient N fertilizer managements, and use of conservation tillage system to sustain soil quality and crop yields (Paustian et al., 2000; Johnson et al., 2007). The reduction in tillage intensity by using NT is one option that can have a positive effect on reducing soil organic C and N mineralization, which can potentially lower CO_2 emission (Drury et al., 2006; Snyder et al., 2009). The use of NT which requires less soil disturbance and increase residue cover may create soil environment under wet condition that is conducive to increase N_2O emission, especially in poorly drained soils causing greater denitrification potential (Linn and Doran, 1984; MacKenzie et al., 1998; Mosier et al., 2002). In annual cropping system such as corn and soybean the use of N fertilizer with corn can be a contributing factor to the rise of N_2O emission (Bouwman, 1996; Pelster et al., 2011). However, the effects of N fertilizer on CO_2 emission were found to be variable (Al-Kaisi et al., 2008).

The storage of loose corn cob residue in field is a new practice and there is limited research on the effect of corn cob residue left on the soil surface on GHG emission. Nevertheless, the storage of corn cob residue may cause changes in soil organic C and N mineralization, thus affecting GHG emission (Cochran et al. 1997; Paustian et al., 2000; Mosier et al., 2002; Chen et al., 2013). Greenhouse gas emission is mostly affected by biological processes such as, availability of C substrate for CO_2, mineral N sources for nitrification or denitrification, soil temperatures, soil water content, and oxygen availability (Butterbach-Bahl et al., 2013). These soil environment parameters can be influenced by type of tillage system that affects soil C and N dynamics (Reicosky, 1997; Al-Kaisi and Yin, 2005; Al-Kaisi and Kwaw-Mensah, 2007). The sustainability of the storage and removal method of corn cob residue will depend heavily on the cropping system (Doran et al., 1984), climate and soil type (Mu et al., 2008), which can be site specific to understand GHG emission as affected by corn cob residue management. We hypothesized that changes in soil biological and physical properties during corn cob residue storage and removal can create soil conditions that may increase GHG emission. Therefore, the objective of this study was to investigate the potential effect of storage and removal of loose corn cob residue on GHG emission and suitable management practices, such as, tillage, N fertilization, corn cob residue amount left on the soil surface, and their interaction effects on GHG emission.

MATERIAL AND METHODS

Experimental sites and treatments

The study was established in the fall of 2010 on a Canisteo silty clay loam (Fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls) and Harps loam (Loam, mixed, superactive, mesic Typic Calciaquolls) soil association at the Iowa State University, Agronomy Research Farm (AC site) located in Central, Iowa (42.0^{o}'N; 93.8^{o}'W) . Before the study was established in the fall of 2010, the AC site was in a corn-soybean [*Glycine max* (L.) Merr.] rotation under conventional tillage, which was chisel plowed in the fall and chisel plow plus disk in the spring. Source of N fertilizer used was liquid urea-ammonium nitrate 32% N (UAN), which was side-dressed injected in May after planting using agronomic rates of 170 kg N ha^{-1} (Blackmeter et al., 1997). Also phosphorus and potassium fertilization were applied as needed to maintain optimum fertility levels so as not to restrict corn or soybean growth.

The average annual temperature and annual precipitation at the AC site for 2011 was 8.7 ^{o}C and 807 mm, respectively. During 2012, the average annual temperature was 11.4 ^{o}C and annual precipitation was 512 mm (Fig.4.1). Treatments were established to monitor the changes in plant growth and development under loose corn cob residue in a randomized complete block design with split-split arrangement with three replications in a continuous corn cropping system for the duration of the study. The dimension of each plot was 6.1 m wide by 7.6 m long with three meter borders between plots and replications.

The AC site consisted of two randomized tillage systems conventional tillage (CT) and no-tillage (NT), which represents the main treatment. Tillage system CT was conducted in the spring within a week after corn cobs residue removal treatment was performed, using a commercially available model with straight shanks and twisted sweeps. The shanks were mounted on four tool bars in a staggering order to ensure an effective spacing of 30 cm between shanks. The depth of tillage with chisel plow was 22-25 cm. A field cultivator was then used for secondary tillage to 10 cm deep, using a horizontal implement frame section with straight shanks and smoothing arrow. The NT system has no disturbance besides application and removal of corn cob residue (removed treatment only), seed planting, and N fertilizer application.

Each tillage system was split into five corn cob residue treatments as Control, Removed Residue (7.5 cm applied in the fall and completely removed early spring), 2.5, 5.0, and 7.5 cm corn cob residue depths randomly assigned at each tillage treatment and replication. The desired corn cob residue treatments were based on our first field evaluation at four different sites in Emmetsburg, Iowa in 2009-2010, where corn cob residue were piled in-field areas of 9.1 m width by 30.5 m long. After, corn cob piles were removed by farmers; noticeable amount of residue ranging from 2.5 to 7.5 cm depth of corn cob residue was left on the soil surface. In the fall of 2010, corn cob residue treatments were established for the 2011 rowing season based on the above observations using loose corn cob residue (70% corn con and 30% corn stalks and leaves) provided by POET Biorefinery from Emmetsburg, Iowa. The corn cob residue for each treatment depth was based on spreading corn cob residue on an experimental plot, which was weighted on a field scale to determine equivalent amount to each designed depth. The corn cob residue equivalent to each treatment depth was then hauled and spread using hand-hoes to each respective plot using a field cart. For the 2012 season, the same corn cob residue treatments were kept on the same plots, except for the removed residue treatment, where fresh corn cob residue was applied again in the fall of 2011 after corn harvest and removed early spring 2012.

Furthermore, each corn cob residue treatment was split to receive three N fertilizer rates of 0, 90, 180, and 270 kg N ha^{-1} randomly assigned at each corn cob residue treatment and replications. The N fertilizer source was 32% liquid UAN (NH_4NO_3), which was side-dressed and injected in May after planting, using a spoke point injector (Baker et al., 1989). The AC site was planted on 6th May, 2011 and14th May, 2012 using a 111 day maturity corn variety (Pioneer, P33W84) with a seeding density of 79,000 seeds ha^{-1}. For the GHG emission measurements only the following treatments of corn cob residue of Control, Removed Residue (7.5 cm applied in the fall and completely removed early spring), 2.5, and 7.5 cm and N fertilizer rates of 0, 180, and 270 kg N ha^{-1} were used

Greenhouse gas emission, soil temperature, and water content measurements

During the growing season from April to October in both years, CO_2 and N_2O emission measurements were taken at 10 days intervals coupled with soil moisture (TRIME-FM Time Domain Reflectometry, Mesa Corp., Medfield, MA) and soil temperature (Digital Thermometer, Fisher Scientific, Waltham, MA) measurements at 7.5 cm soil depth at each experimental plot following the GHG sampling protocol of GRACEnet Chamber-based Trace Gas Flux Measurement (Parkin and Venterea, 2010). In each plot, one PVC ring (30 cm diameter and 10 cm high) was placed on the soil surface to a depth of approximately 7.5 cm. All rings were placed directly on top of the UAN band between plant rows. The flux measurements were performed by placing matching vented chambers on top of the PVC rings, and then gas samples were taken at 0, 20, and 40 min intervals after chamber deployment. During these intervals, a 10 mL gas sample was collected using a polypropylene syringe and immediately injected into evacuated glass vials (10 mL) fit with plastic caps and septa rubber stoppers. Measurements were taken between 800 and 1400 hours to approximate the 24 hours mean soil surface CO_2 and N_2O emission. Gas samples concentrations were determined with a gas chromatography instrument (GC system Model 7890A, Agilent Technologies, Santa Clara, CA).

Cumulative soil surface CO_2 and N_2O emission for the growing season were calculated using the following equation (Grote and Al-Kaisi, 2007):

$$\text{Cumulative } CO_2 \text{ (kg ha}^{-1}\text{)} \textit{ or } N_2O \text{ (g ha}^{-1}\text{)} = \sum_i^n \frac{(X_i + X_{i+1})}{2} * (t_{i+1} - t_1) \qquad [1]$$

where, X_i is the first CO_2 or N_2O emission (kg ha^{-1} d^{-1} or g ha^{-1} d^{-1}, respectively) reading, and X_{i+1} is the following reading at times t_i and t_{i+1}, respectively; n is the last CO_2 or N_2O emission reading during the growing season and i is the first CO_2 or N_2O emission reading in the growing season.

Soil mineral nitrogen measurements

Soil mineral N (NO_3–N and NH_4–N) samples were collected at the same time GHG emission measurements were taken. Six 1.7 cm diameter soil cores were taken at each treatment plots for the top 15 cm depth in the same vicinity of each PVC ring. Soil samples were then taken to the lab and immediately sieved through 4 mm sieves at field moisture condition. Then 10 g of soil sample was placed in a 125 mL Nalgene bottle, where 50 mL of 2 M KCl was added to each soil sample bottle and shaken for 30 min (Mulvaney, 1996). The extraction solution was then filtered through a Whatman No. 42 110 mm filter paper into a 20 mL scintillation vial. The filtered solution was stored at -4°C in a freezer until ready to be analyzed for NO_3–N and NH_4–N with the Lachat QuickChem 8000FIA+ (Lachat Instruments, Milwaukee, WI) at the soil testing laboratory at the Agronomy Department, Iowa State University.

Statistical analysis

Data was analyzed using the statistical analysis procedure PROCMIXED (SAS Institute, 2002). Type of tillage was considered the main plot treatment and different corn cob residue levels and N rates as split-split-treatments by year. Mean separation was determined using the PDIFF procedure and significance values were determined at $p \leq 0.05$.

RESULTS AND DISCCUSION

Cumulative soil N_2O emission

Soil cumulative N_2O emission was affected by different corn cob residue treatments and N rate in both years, but no difference between tillage systems effects on N_2O emission was observed (p=0.1038 and p=0.4536 for 2011 and 2012, respectively). Also, no differences were observed in seasonal cumulative N_2O emission across all corn cob residue treatments within each N rate in both years (Table 1). In 2011, an average across all corn cob residue treatments showed a cumulative N_2O emission for 0, 180, and 270 kg N ha^{-1} throughout the growing season of 130, 2630, and 3721 g N_2O ha^{-1}, respectively. However in 2012, the average cumulative N_2O emission across all corn cob residue treatments for the same N rates were 28, 832, and 776 g N_2O ha^{-1}, respectively, with considerable decline from 2011. The increase in N_2O emission was as a result of increase in N rate and soil moisture availability as main drivers for N_2O emission (Parkin and Kaspar, 2006; Bouwman, 1996; Pelster et al., 2011). Also an average across all N rates show a cumulative N_2O emission in 2011 for control, removed, 2.5 cm, and 7.5 cm corn cob residue treatments of 2070, 1878, 2243, and 2450 g N_2O ha^{-1}, respectively. However, in 2012 the averages across N rates for the same corn cob residue treatments for N_2O emission were 175, 331, 513, and 1161 g N_2O ha^{-1}, respectively. These differences in N_2O emission between 2011 and 2012 highlight the seasonal moisture variability and the effect of high amount of corn cob residue in providing suitable moisture condition increasing N_2O emission as compared to lower amounts of residue.

The low cumulative N_2O emission in 2012 can be attributed to the drought condition and specifically during the months of May, June, and July, when the site received on average 40 mm less rainfall and air temperature was 5 °C higher compared to 2011 growing season (Fig. 4.1) (Goodroad and Keeney, 1984; Lemke et al., 1999). Also, it was observed that the increase in soil N_2O emission with the increase of N rate and corn cob residue treatments, where soil NO_3-N becomes greater as both N rate and corn cob residue amount increased. Greater soil N_2O emission with the increase in corn cob residue depth can be attributed to the corn cob effect in increasing soil moisture and the availability of soil NO_3–N and NH_4–N concentrations, which are major factors in controlling nitrification and denitrification, respectively, thus altering soil N_2O emission (Chen et al., 2013).

Soil N_2O emission rate

Seasonal soil N_2O emission rates during 2011 and 2012 growing seasons were affected by corn cob residue treatments and N rate. There were no differences between tillage systems effects on soil N_2O emission rate in both years ($p=0.5449$ and $p=0.8125$ for 2011 and 2012, respectively). The highest soil N_2O emission rate occurred approximately two weeks after N fertilizer application, which also coincided with the first rainfall event of the season and the increase in soil moisture content (Fig. 4.2 and 4.3). The increase in soil moisture created anaerobic condition for denitrification, leading to an increase in soil N_2O surface emission (Mosier et al., 2002). In general, the 2.5 cm and 7.5 cm corn cob residue treatments caused greater soil N_2O emission than the control and removed treatments in both years. Some studies suggested that the increase in N_2O emission with the increase in crop residue cover can be due to increase in soil moisture that leads to anaerobic condition (Chen et al., 2013). Differences in N_2O emission rate across corn cob residue treatments are expected, where soil moisture condition and mineral N concentration are factors in controlling soil N_2O emission rate (Sainju et al., 2012).

Differences in seasonal soil mineral N concentration, soil moisture content, and soil temperature were observed between both years. In 2012, seasonal soil mineral N concentration was significantly lower than that in 2011 across all corn cob residue treatments and N rates. Also, higher soil temperatures and low soil moisture content were observed throughout the growing season in 2012. These conditions were reflected in the low soil surface N_2O emission rate in 2012. However, high N_2O emission rates in 2012 were associated with rain events and high N rate as main drivers in contributing to soil N_2O emission high peaks (Parkin and Kaspar, 2006; Bouwman, 1996; Pelster et al., 2011).

Cumulative soil CO_2 emission

The cumulative surface CO_2 emission throughout the growing season was affected by the interaction of corn cob residue treatments and tillage system in both years, with no differences due to N rate ($p=0.5193$ and $p=0.6819$ for 2011 and 2012, respectively). In general, the average cumulative CO_2 emission associated with both CT and NT systems across all corn cob residue treatments in 2011 was similar, 30161 and 30369 kg CO_2 ha^{-1}, respectively. However, in 2012, the cumulative CO_2 emission was different for both tillage systems, where average CO_2 emission from CT across all corn cob residue treatments was 8825 kg CO_2 ha^{-1} compared to 11480 kg CO_2 ha^{-1} with NT. The difference in cumulative CO_2 emission between CT and NT across all corn cob residue treatments in 2012 can be attributed to the dry conditions and low soil water content in CT system as compared to NT system, where in the months of May, June, and July of 2012, the site received on average 40 mm less rainfall and air temperature was 5 °C higher compared to

2011 growing season (Fig. 4.1). Also, the CT soil water content across all corn cob residue treatments averaged 22 cm^3 cm^{-3}, where NT averaged 28 cm^3 cm^{-3}. Previous research findings suggested a reduction in CO_2 production at low soil water content (Linn and Doran, 1984; Fortin et al., 1996; Chen et al., 2013). Also, differences in cumulative CO_2 emission within each tillage system for different corn cob residue treatments were observed in 2011. In general, the highest cumulative CO_2 emission was observed from the 7.5 cm corn residue depth treatment with both CT and NT systems compared to the rest of corn cob residue treatments. Also, treatments covered with 2.5 cm corn cob residue showed greater cumulative CO_2 emission than the control and removed corn cob residue treatments (Table 2). In 2012, there was no difference in cumulative CO_2 emission across all corn cob residue treatments under CT. However, under NT residue treatment with 7.5 cm corn cob residue showed greater cumulative CO_2 emission compared to the control and removed under NT and CT across all corn cob residue treatments. These differences can be attributed to the effect of corn cob residue in conserving soil moisture (Chen et al., 2013), especially with NT as compared to CT, where corn cob residue was incorporated in soil and becoming less effective in conserving soil moisture as a driver for increasing CO_2 emission.

Soil CO_2 emission rate

Generally, CO_2 emission rate was affected by corn cob residue treatments and tillage system. There were no differences between soil CO_2 emission rates of different N rates in both years (p=0.0720 and p=0.9965 for 2011 and 2012, respectively) (Fig. 4.4 and Fig. 4.5). Greater CO_2 emission rates were observed during the 2011 growing season than in 2012. This could be attributed to the dry condition and extreme low soil water content during summer 2012 leading to slow down in microbial activities and low mineralization rate of soil organic C (Mosier et al., 2002; Hernandez-Ramirez et al., 2009). However, it was observed that high CO_2 emission rate occurred in the subsequent days after rain events where soil moisture increase is observed. This delay in CO_2 emission peak rate could be attributed to the time lag in plant root respiration in response to soil moisture availability in both years (Sainju et al., 2012). In general, seasonal CO_2 emission rates were greater under 2.5 cm and 7.5 cm corn cob residue compared to the control and removed corn cob residue treatments in both years. The increase in CO_2 emission rate with 2.5 cm and 7.5 cm corn cob residue treatments under CT and NT in both years can be attributed to increase in C input, microbial activity, and C mineralization (Dick et al., 1992).

CONCLUSIONS

The amount of corn cob residue left on the soil surface had an effect on N_2O and CO_2 emission, where high cumulative emission and rate were associated with high amounts of corn cob residue left on the soil surface regardless of N rate during the growing season. This increase in N_2O and CO_2 emission with high amount of corn cob residue on the soil surface can be attributed to high soil moisture content and moderation of soil temperature during dry condition. The increase in N_2O emission generally coincided with greater N rate and soil mineral N concentration across all corn cob residue treatments. However, no such effect was observed on CO_2 emission. In general, tillage system showed minimum effect on N_2O emission, but under dry condition differences in CO_2 emission under different tillage systems were observed, where CO_2 emission was much greater with NT as compared to CT. Also, the increase in CO_2 emission coincided with rain events due to increase in root respiration as a contributing factor to total CO_2 emission. These findings suggest that the amount of corn cob residue left on the soil surface can cause an increase in CO_2 and N_2O emission due to changes in soil environment and in particular soil moisture content and soil temperature. Therefore, an adequate cleanup of loose corn cob after storage in the field can reduce soil CO_2 and N_2O emission.

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Table 4.1. Cumulative soil surface N_2O emission from April to October across tillage system as affected by corn cob residue treatment and nitrogen rate in 2011 and 2012 at Ames, Iowa site.

		Cumulative N_2O	
Corn Cob Residue	N Fertilizer	2011	2012
	Kg N ha^{-1}	-------N_2O g ha^{-1}-------	
Control	0	79e	20d
Removed	0	70e	20d
2.5 cm	0	189e	27d
7.5 cm	0	181e	43d
Control	180	2289d	157d
Removed	180	2961bcd	552cd
2.5 cm	180	2406d	619cd
7.5 cm	180	2863bcd	1998a
Control	270	3843abc	347cd
Removed	270	2602cd	420cd
2.5 cm	270	4133ab	893bc
7.5 cm	270	4305a	1443ab

* Least significant means with the same letter within each year are not significantly different at $p \leq 0.5$.
Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.

Table 4.2. Cumulative soil surface CO_2 emission from April to October across nitrogen fertilizer rates as affected by tillage and corn cob residue treatment in 2011 and 2012 at Ames, Iowa site.

		Cumulative CO_2	
Tillage System	Corn Cob Residue	2011	2012
		---------CO_2 kg ha^{-1}---------	
CT	Control	22199c	5745c
CT	Removed	17124c	11131ab
CT	2.5 cm	36243b	10952ab
CT	7.5 cm	45077a	7471bc
NT	Control	18711c	11708ab
NT	Removed	21713c	8287bc
NT	2.5 cm	31894b	10678ab
NT	7.5 cm	49159a	15248a

* Least significant means with the same letter within each year are not significantly different at $p \leq 0.5$.
Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.
CT is conventional tillage; NT is no-till.

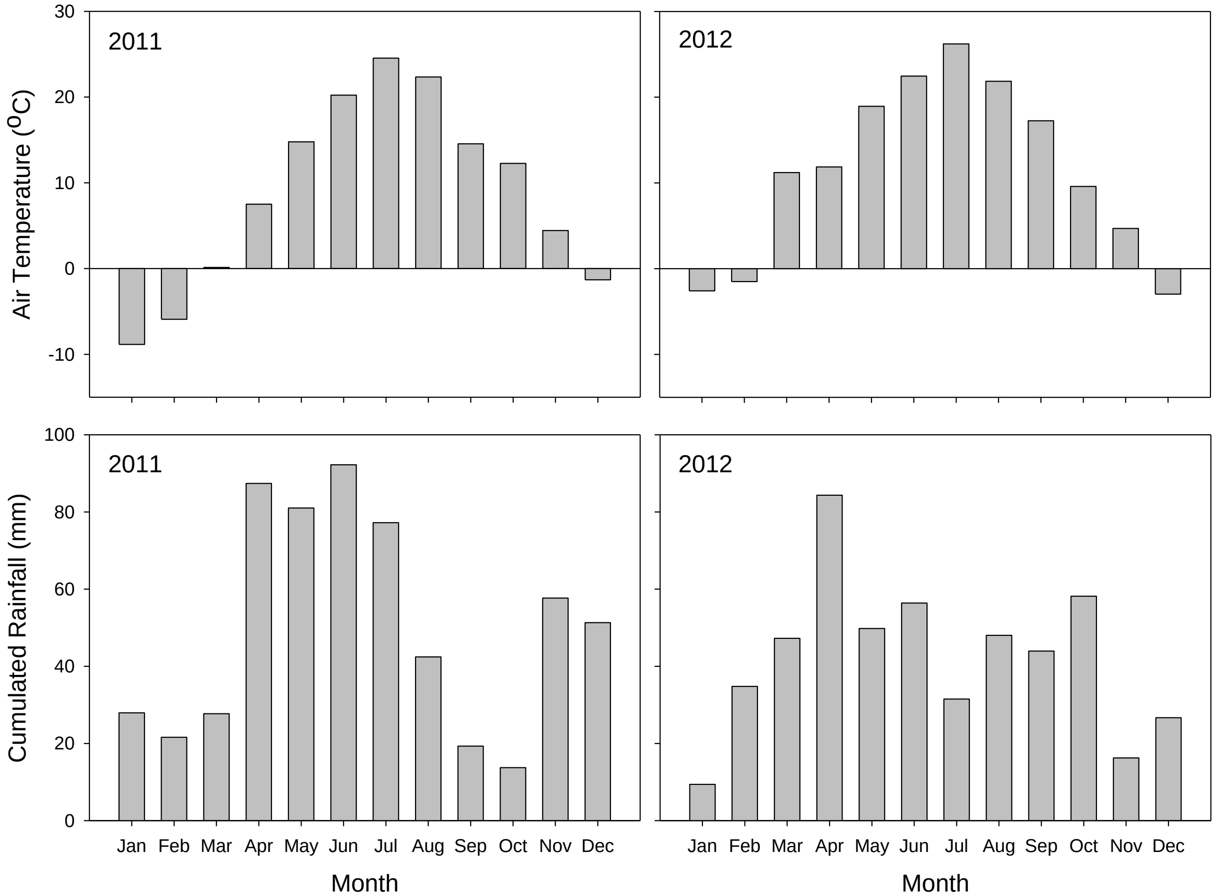

Figure 4.1. Average monthly air temperature and rainfall for 2011 and 2012 at Ames, Iowa site.

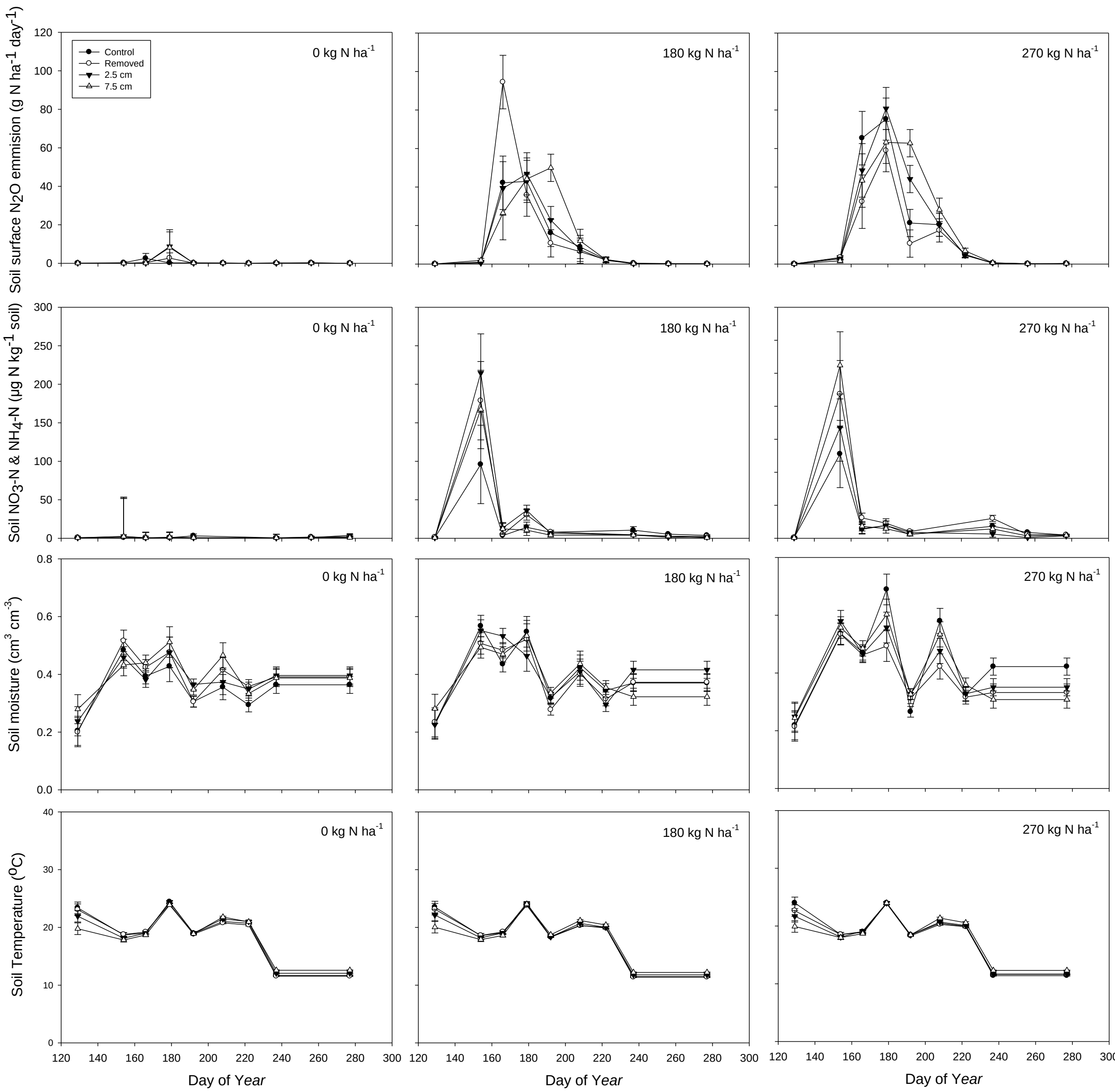

Figure 4.2. Corn cob residue and N fertilizer rate effects on N_2O emission as influenced by soil water content, soil temperature, and mineral nitrogen concentration across NT and CT tillage system for 2011 at Ames, Iowa site.

Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.

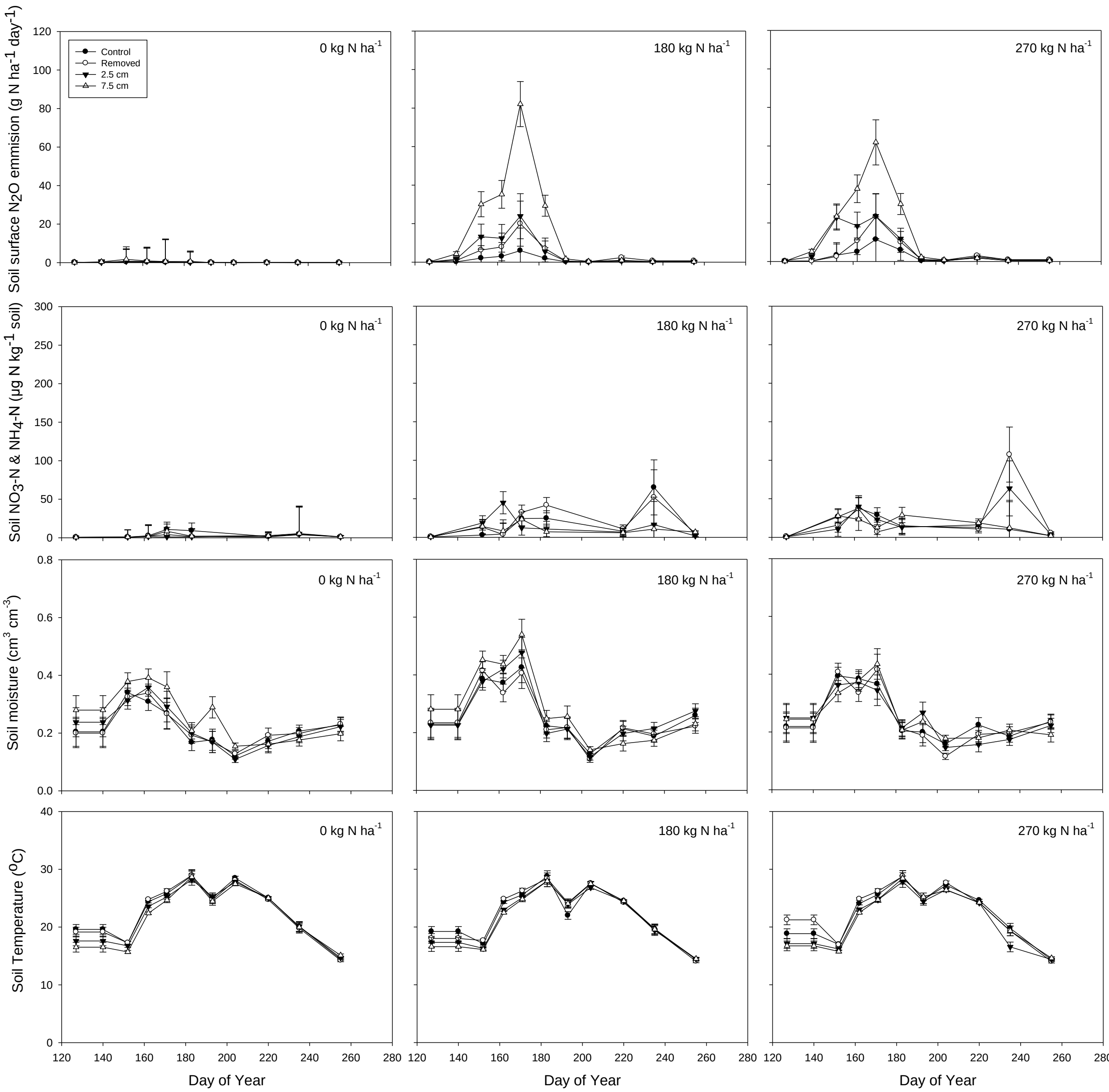

Figure 4.3. Corn cob residue and N fertilizer rate effect on N_2O emission as influenced by soil water content, soil temperature, and mineral nitrogen concentration across NT and CT tillage system for 2012 at Ames, Iowa site.

Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.

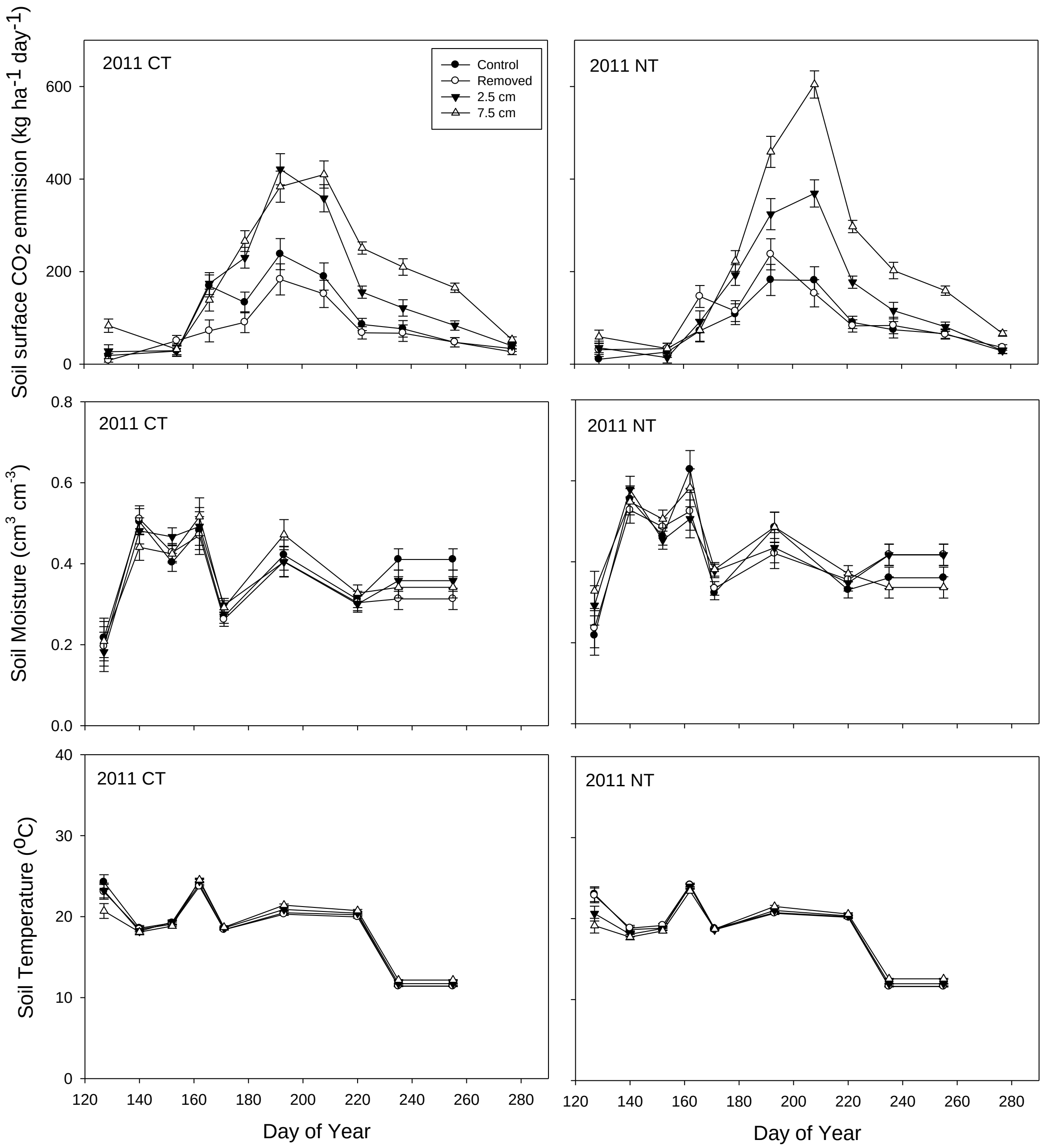

Figure 4.4. Corn cob residue and tillage system effects on CO_2 emission as influenced by soil water content and soil temperature across N fertilizer rates for 2011 at Ames, Iowa site.

Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.
CT is conventional tillage; NT is no-till.

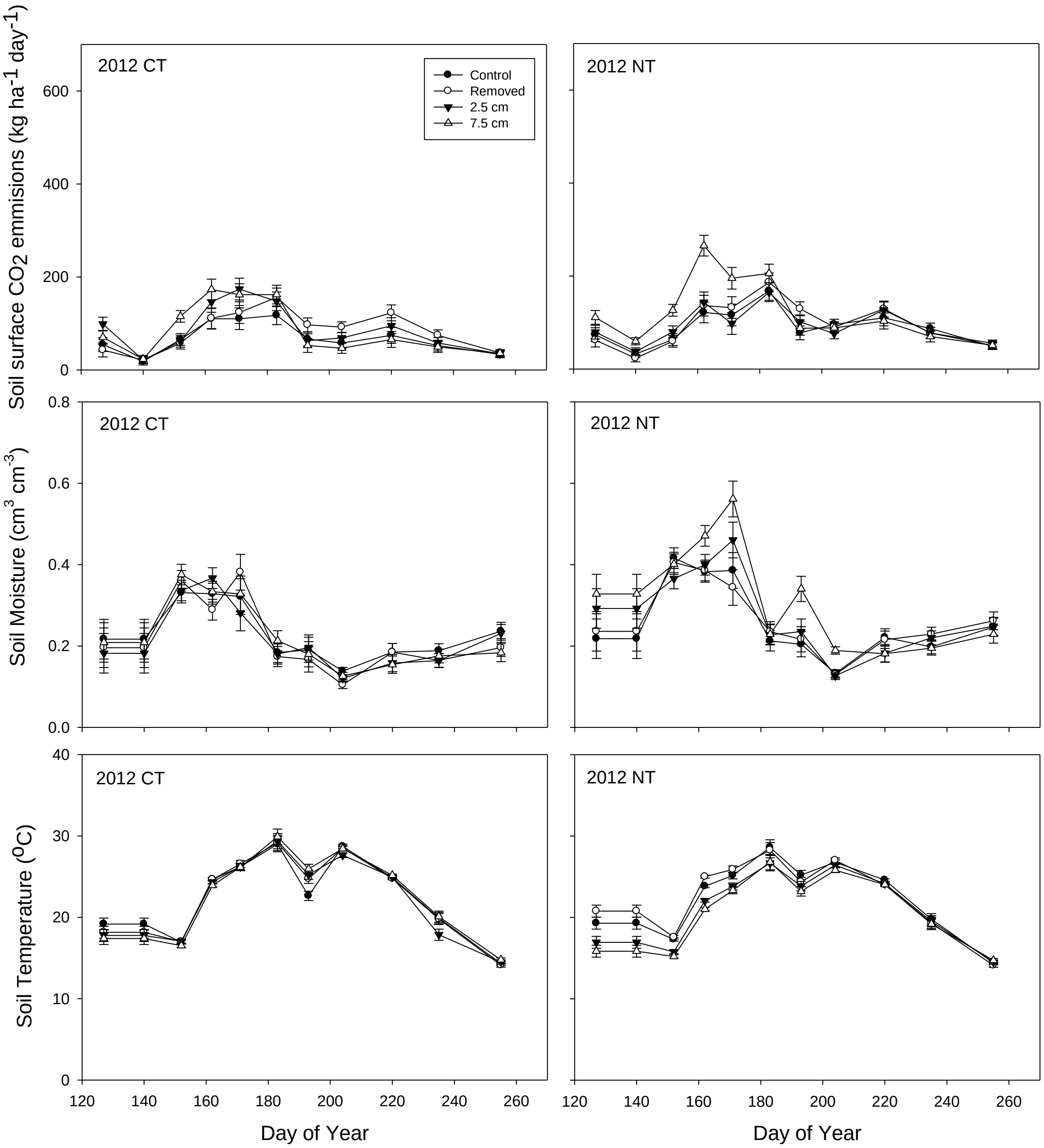

Figure 4.5. Corn cob residue and tillage system effects on CO_2 emission as influenced by soil water content and soil temperature across N fertilizer rates in 2012 at Ames, Iowa site.

Control is no corn cob residue applied or removed.
Removed is 7.5 cm corn cob residue depth applied in the fall and completely removed early spring,
2.5 cm is corn cob residue depth applied.
7.5 cm is corn cob residue depth applied.
CT is conventional tillage; NT is no-till.

CHAPTER 5

GENERAL CONCLUSIONS

Storage methods include piling and baling of loose corn cob residue at the edge of harvested fields over the winter. Unfavorable plant growth responses have been observed with storing corn cob residue in the field. The objectives of this study were to examine how tillage, N fertilizer rates, corn cob residue, and their interaction effects on (i) plant development and productivity, (ii) soil physical, biological, and chemical properties, and (iii) GHG emission to determine feasible strategies to manage corn cob residue effects on plant growth and soil health. After two years of evaluating loose corn cob and corn cob residue mix bales field storage and removal with suite of management practices, including tillage and N fertilization rates, the following conclusions and recommendations can be made based on the field findings from two sites studies.

Loose Corn Cob

Findings of the loose corn cob residue study suggest that plant growth and development parameters such as, ERI, extended plant leaf heights, aboveground biomass, plant population, and grain yield were mostly affected by the density or depths of loose corn cob residue left on soil surface after corn cob residue removal throughout the growing season. Also, plant vegetative growth stages were affected negatively by the presence of corn cob residue early in the season; however such effect disappeared as the plants reached full growth. Above-ground biomass and grain organic C and N concentrations were mostly affected by the increase of N fertilizer rates; however, corn cob residue treatments and tillage systems showed no differences during the study. Additionally, soil chemical properties such as, SOC, STN, pH, organic acids concentrations were not affected by the presence of corn cob residue on the soil surface during the short time of this study. However, positive changes in SOC and STN contents were observed at the top 0-7.5cm of soil depth across all corn cob residue treatments, but at lower depths SOC and STN contents declined. It was observed that soil MBC concentrations were affected by corn cob residue treatments, where higher MBC concentrations were found in areas with corn cob residue on the soil surface, especially in June and July (mid-summer).

Also, corn cob residue treatments showed no effect on aggregate distribution within each size fraction during the two years. However, findings of WSA percent showed that soil macro-aggregates fractions and associated C content decreased across all corn cob residue treatments by the end of the study. The increase in the amount of corn cob residue left on the soil surface as with 7.5 cm corn cob residue caused decrease in ρ_b compared to lower amounts of residue treatments across all soil depths. Furthermore, findings revealed that the complete removal of corn cob residue from the field, regardless of the tillage system caused an increase in SPR throughout the soil profile. Residue clean-up and corn cob residue removal increased soil compaction, ρ_b, and reduction in macro-aggregates when removal practices are conducted in the same field on yearly basis. Another parameter affected by corn cob residue treatments is water infiltration rate (I_r), where N fertilizer rates have little effect on improving I_r, but the increase in residue level left on the soil surface contributes to the increase of I_r, especially with CT system. Results of GHG emission showed that N_2O emission was affected by N fertilizer rate and corn cob residue treatments, but soil CO_2 emission was affected by tillage systems and corn cob residue. In general, treatments with 2.5 cm and 7.5 cm corn cob residue depth generated greater soil CO_2 and N_2O emission than the control and removed residue across both tillage systems and N fertilizer rates, respectively. High soil N_2O emission rates coincided with high N rates and soil mineral N concentration across all corn cob residue treatments. However, under dry condition soil CO_2 and N_2O emission across corn cob residue treatments were low, where soil moisture can be a limiting factor for soil N_2O and CO_2 emission. However, soil CO_2 emission rate peaked in mid to late July and especially after rain events, where soil moisture and temperature are adequate.

Corn Cob Bales

After two years of corn cob bales storage and removal, findings show that plant growth and development were not greatly affected by corn cob residue left after bales removal. However, ERI, extended plant leaf heights, plant population, vegetative growth stages, aboveground biomass, and grain yield where corn cob bales were placed showed slightly lower values than the control treatment. Also, no differences were observed in organic C and N concentrations of the aboveground biomass and grain during the study. The residue left on the soil surface after bales removal showed no effect on SOC and STN contents regardless of the residue treatment and N fertilizer rate. However, positive change in SOC and STN contents was observed at the top 7.5 cm soil depth and a declining trend at the lower depths. Also, soil pH and MBC values were not affected by residue treatments, removal of bales, and N fertilizer rate over the two years study. However, greater MBC values were observed in the fall in both years across all management treatments than early spring. The N fertilization and corn cob bales residue removal treatments showed limited effects on WSA and their associated C content. However, soil macro-aggregates stability and associated C content across all corn cob residue treatments showed a decline by the end of the experiment, while an increase in micro-aggregates and their associated C was observed. The reduction in soil macro-aggregates by the end of the study was indicated by the reduction in MWD values over time across all corn cob residue treatments.

Greater ρ_b and SPR values were mostly found at lower depths in areas where corn cob bales were stored.

It is important to keep in mind that these finding are just for two years of corn cob residue treatments study. According to the study findings, the most mitigating practices in reducing corn cob residue (loose and bales) effects on plant growth and development, soil physical, biological, and chemical properties, and soil CO_2 and N_2O emission (especially with loose corn cob treatments) are adequate control of field machinery traffic during corn cob residue removal process by avoiding wet soil condition. Loose or baled corn cob residue storage and removal from the field should be particularly monitored, in order to minimize its effects on plant growth and development and soil health. Also, proper soil testing and N fertilization application is critical to insure N availability to overcome N immobility due to corn cob residue effects after loose cobs and bales removal from the field.